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Kuskokwim River Sockeye Salmon Investigations, 2006 and 2007

Edited by:

Sara E. Gilk,

Douglas B. Molyneaux,

and

Zachary W. Liller

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CHAPTER 1. ADULT SOCKEYE SALMON DISTRIBUTION, STOCK-SPECIFIC RUN TIMING, AND STOCK-SPECIFIC MIGRATION RATE

by

Sara E. Gilk

Douglas B. Molyneaux

Daniel B. Young

and

Toshihide Hamazaki

ABOUT THE AUTHORS

Sara Gilk and Douglas Molyneaux are fisheries biologists, and Toshihide Hamazaki is a biometrician with the ADF&G, Division of Commercial Fisheries, 333 Raspberry Rd, Anchorage, AK 99518-1599

Daniel Young is a fisheries biologist with the National Park Service, Lake Clark National Park and Preserve, General Delivery, Port Alsworth, AK 99653

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ABSTRACT

The role of sockeye salmon in the environment and their importance to the culture and economy of the Kuskokwim River is changing. There is growing interest in directed commercial harvest of this species as demonstrated by recent actions taken by the Alaska Board of Fisheries that will allow directed commercial harvest on sockeye salmon under a guideline harvest level. Lacking, however, is fundamental knowledge about distribution, abundance, and basic biology and ecology of sockeye salmon in the Kuskokwim River. Our goal was to begin addressing these data gaps by describing the relative spawning distribution, stock-specific run timing, and stock-specific migration rate. We achieved these objectives by conducting radiotagging studies in 2006 and 2007. Results indicate that river-type sockeye salmon are far more prevalent than previously believed, particularly those spawning in the Holitna River basin, which accounted for about 70% of the final destination of tagged fish. Other major contributors included the Stony River (lake-type), and Aniak River (river-type). River-type sockeye salmon tend to have more volatile productivity than lake-type populations, so given the dominance of river-type fish, fisheries managers should anticipate highly variable annual returns that may be difficult to forecast. Stock-specific run timing for the three major stocks overlapped broadly, which will provide additional management challenges to ensure adequate escapement between stocks that likely have very different productivity. Future measures should include establishing an escapement monitoring program representative of the stock diversity found within Kuskokwim River sockeye salmon, including escapement goals.

Key words: Holitna River, Stony River, Aniak River, Aniak Lake, Kogrukluk River, Telaquana Lake, Necons River, Two Lakes, Kuskokwim River, distribution, stock-specific, run timing, migration rate, radiotelemetry, tagging, fish wheels, weirs, subsistence fishing, commercial fishing, salmon fishery management, sockeye salmon, *Oncorhynchus nerka*

INTRODUCTION

Five species of anadromous Pacific salmon *Oncorhynchus* spp return to the Kuskokwim River each year and support an average annual subsistence and commercial harvest of nearly one million fish, with sockeye salmon *O. nerka* accounting for only about 70,000 (range 26,000–162,000) of the harvest (Whitmore et al. 2008). In recent years, however, long-time residents of the Kuskokwim River have noted an increase in the occurrence of sockeye salmon as a subsistence food (James Charles, resident, Tuntutuliak, personal communication). There has also been interest in developing a directed commercial sockeye salmon fishery, which prompted the Alaska Board of Fisheries in 2004 to formally establish a limited annual guideline commercial harvest level of 0–50,000 sockeye salmon (5 AAC 07.365; Bergstrom and Whitmore 2004). In accordance with the Alaska Sustainable Salmon Policy (5 AAC 39.222), fishery managers must use a precautionary approach in implementing this sockeye salmon directed fishery because of the lack of fundamental information about sockeye salmon distribution, abundance, and run dynamics. Indeed, at the time of this study, there were no escapement goals established for sockeye salmon in the Kuskokwim River, and sockeye salmon generally had a low occurrence at the current array of tributaries where salmon escapements were monitored.

Of the tributaries monitored (Figure 1.1), the largest numbers of sockeye salmon occur at the Kogrukluk River weir located in the upper Holitna drainage, where annual escapements ranged from 1,700 to 60,000 fish (Liller et al. 2008). Kwethluk River ranks second with annual escapements ranging from a few hundred to 6,732 fish (Miller et al. 2007, 2008). Sockeye salmon number fewer than 1,000 fish in the Tuluksak, George, Tatlawiksuk, and Takotna rivers as evidenced by weir counts. Like most of the Kuskokwim River drainage, neither Kogrukluk nor Kwethluk rivers have the large lakes that are typically associated with significant production (Burgner 1991), so sockeye salmon occurrence at these and other monitored tributaries had been thought incidental. Most Kuskokwim River sockeye salmon production was assumed to have been from Telaquana Lake, in the upper Stony River drainage, where observations of sockeye salmon are periodically documented from aerial surveys, though viewing conditions are nearly always poor due to suspended glacier flour (Burkey and Salomone 1999).

Sockeye salmon exhibit a variety of life history strategies throughout their range. They are typically associated with rivers that provide access to lake habitat where juveniles rear for one to two years prior to smolting, referred to as following a "lake ecotype" life history strategy (Wood et al. 2008). Sockeye salmon from tributaries with no associated lake system follow the "river ecotype" life history strategy where, following emergence, juveniles rear and overwinter in river channel and slough habitats where water velocity is slow. River-type populations are not abundant across the Pacific Rim, though small populations are reported throughout much of the species range (e.g., Wood et al. 1987; Burgner 1991; Gustavson and Winans 1999; Eiler et al. 1992). Some watersheds also produce 0-check or "sea ecotype" sockeye salmon that spend at most a few months after emergence in river habitats before smolting (Wood et al. 2008). These three life history strategies likely reflect differences in productivity as demonstrated by differences in sizes, ages, and fecundities of spawning adults (Rogers 1987; Blair et al. 1993), in high heterogeneity in sizes of riverine juveniles (Wood et al. 1987), and differences in genetic diversity and genetic structure (Beacham et al. 2004; Gustafson and Winans 1999; McPhee et al. 2009).

Given these different life history strategies and the likely resulting differences in productivity, it is important to have knowledge of stock-specific run timing through mixed-stock fisheries such as in the lower Kuskokwim River. In other rivers, differences in run timing have been seen between spawning aggregates (stocks), most often noted between tributary spawning- and lake-spawning populations (Burger et al. 1995). An overlap in run timing of specific populations and life history types may be a concern for harvest managers, since the capacity and productivity of different stocks may vary (Merritt and Roberson 1986). Overharvest of smaller spawning aggregates could result in depression or elimination of some populations (e.g., Policansky and Magnuson 1998). Previously, there has been very little information on the spawning distribution, relative abundance, or stock-specific run timing of Kuskokwim River sockeye salmon with which to base sustainable management practices.

OBJECTIVES

In this study, we used radiotelemetry based at the Kalskag fish wheel tagging platform in 2006 and 2007 to achieve the following:

1. Describe the distribution and relative abundance of spawning sockeye salmon aggregates (stocks) among tributaries of the Kuskokwim River upstream of Kalskag (rkm 270).
2. Estimate stock-specific run timing and stock-specific migration rates in the mainstem Kuskokwim River.
3. Describe the relative importance of river-type versus lake-type sockeye salmon to total sockeye salmon production in the Kuskokwim River.

METHODS

CAPTURE AND TAGGING

Adult sockeye salmon were captured in 2006 and 2007 on the mainstem Kuskokwim River (Figure 1.1), fitted with radio and/or anchor tags, and tracked to locations throughout the drainage using aerial and ground-based tracking. Captures were made at approximately rkm 270 using two fish wheels operated from early June to mid-August. This platform has tagged fish since 2001 and is the farthest downstream point above commercial fishing districts where fish wheels are effective to capture salmon (Schaberg et al. 2010). Fish wheels were operated seven days per week in 2006, and six days per week in 2007, for about nine hours each day during daylight hours. One fish wheel was located along the north bank and one along the south bank, each was equipped with a live box for holding fish prior to tagging. Throughout each day, a two to three person crew rotated between two fish wheels to remove fish from the holding box and deploy tags. At each inspection, all fish were netted from the live box, the number of each species caught was recorded, and species other than sockeye salmon were immediately released. Each time a sockeye salmon was netted, it was immediately placed in a tagging cradle that was submerged in a tub of continuously refreshed river water. Fish were not anesthetized.

Fish were tagged with pulse-coded esophageal radio transmitters manufactured by Advanced Telemetry Systems (Isanti, Minnesota).[2] Transmitters were individually distinguishable by a unique encoded pulse pattern and frequency. Ten frequencies spaced approximately 20 kHz apart with 50 encoded pulse patterns per frequency were used for a total target of 500 uniquely identified tags in each year of the study. Radio tags were inserted through the esophagus and into the upper stomach using a narrow piece of polyvinyl chloride (PVC) tubing so that the antenna end was seated approximately 0.5 cm anterior to the base of the pectoral fin. Results from a 2005 feasibility study suggest that tagging fish <400 mm mideye to fork (MEF) length results in a higher potential risk of stomach rupture (Appendix 1.A); therefore, fish shorter than 400 mm MEF length were not tagged in this study (estimated <7% of the population based on length measurements taken at the Kalskag tagging site in 2002 and 2003).

Efforts were made to distribute radio tags over the duration of the run and in proportion to run strength by developing a deployment schedule based on fish wheel catches in previous years (Kerkvliet and Hamazaki 2002; Kerkvliet et al. 2003; Pawluk et al. 2006a, 2006b). Attempts were also made to tag fish in equal proportion along the north and south banks to ensure that all spatial components of the run had a non-zero probability of capture. Holding time in fish wheel live boxes has been shown to have an effect on fish recovery from the tagging procedure (J. Eiler, NOAA/NMFS, personal communication; Appendix 1.A), so efforts were made to limit holding time (time of capture though time of release) to less than one hour for all radiotagged sockeye salmon. Fish that were obviously injured, appeared excessively stressed, or were held more than one hour were not radiotagged.

In addition to an internal radio transmitter, all radiotagged fish were given a secondary mark of a uniquely numbered fluorescent colored anchor tag inserted near the dorsal fin (Guy et al. 1996). These anchor tags helped facilitate visual identification of radiotagged fish at the various recovery sites. Three scales were removed from the preferred region for age analyses (Devries and Frie 1996). Ages were later determined from scale patterns as described by Mosher (1969). A tissue sample from the axillary process was taken and stored in 100% ethanol for future genetic stock identification analyses. Information on sex, MEF length, condition of fish, and hold time were recorded. At the time of tagging, a record of each tag deployment was keyed into an electronic data logger including: the unique tag number, tag color, sex, MEF length, condition of fish, and holding time. Fish were released immediately after tagging.

In order to examine possible tag deployment biases, all captured sockeye salmon that did not receive the radio/anchor tag combination, were tagged with a single uniquely-numbered

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[2] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

fluorescent anchor tag inserted into the musculature just ventral to the dorsal fin (Guy et al. 1996). For fish that only received an anchor tag, the tag was color-coded to distinguish between fish tagged from the north and south bank fish wheel. The primary focus of this study relates to findings from the radio tag deployments; findings from anchor tag deployment are discussed in Appendix 1.B.

TAG RECOVERY AND TRACKING

Radiotagged sockeye salmon were tracked using both ground-based receiver stations and aerial tracking surveys. Seventeen ground-based stations were strategically distributed throughout the Kuskokwim River drainage, including the lower end of major spawning tributaries, and at escapement weirs (Figure 1.1). Each station consisted of several integrated components, including a computer-controlled ATS Model 4500 receiver and self-contained power system similar to Eiler (1995). Receivers were programmed to scan through frequencies at 6-second intervals. When a signal of sufficient strength was detected, the receiver paused for 12 seconds on each of two antennas (one oriented upstream and one downstream), and then the receiver recorded date and time the fish was present, signal strength, activity (active or inactive), and location of the fish relative to the station location (upstream or downstream). Receiver data were periodically downloaded to a laptop computer or transmitted to a NOAA geostationary operational environmental satellite (GOES) and downloaded via the internet.

Aerial tracking included coverage of the mainstem Kuskokwim River, major tributaries, and many smaller tributaries. The intention of the aerial tracking was to locate radiotagged fish that had not yet migrated into a spawning stream (including fates such as tag loss, handling mortality, or harvest); locate tagged fish in spawning tributaries other than those monitored with tracking stations; locate fish that ground-based stations failed to record; and validate records from the ground-based stations. Two drainagewide aerial tracking surveys were conducted each year, one in July and another in August, plus a third survey was conducted in early September that concentrated on the mainstem Kuskokwim and a few tributaries. The timing of aerial tracking events bracketed the period when most sockeye salmon were likely to be on spawning grounds based on previous tagging experience (Schaberg et al. 2010) and timing of sockeye salmon at tributary weir locations (e.g., Liller et al. 2008). Surveys were conducted in a fixed-winged aircraft flown at an altitude that ranged from 100 to 300 m above the ground surface, with one or two observers using ATS Model 4500 receivers. Two H- or Yagi antennas, each connected to a switching box, were mounted on the aircraft with one antenna placed on each wing strut. Antenna placement was such that the antennas detected peak signals perpendicular to the direction of travel. Dwell time on each transmitter frequency was one to two seconds. Once a tag was located, its frequency, code, and latitude/longitude were recorded by the receiver.

Radio and anchor tags were also recovered from fish captured in subsistence and sport fisheries. Recovered radio tags were re-deployed and voluntary tag recoveries were included in the stock-specific run timing analysis when applicable. To encourage tag returns, we conducted a postseason lottery each year. Each tag was printed with a toll-free number and address for reporting tag recoveries and for entering the lottery.

DATA ANALYSES

Findings from radio tag deployment were used to describe the distribution of sockeye salmon upstream of Kalskag, to describe stock-specific run timing past the tagging site, and to describe stock-specific migration rates. "Stock" as used here either refers to spawning aggregates from large tributaries sub-basins such as the Holitna River or smaller drainages within these sub-basins such as the Kogrukluk River. Though not a formal part of the study, we also explored the feasibility of estimating total inriver abundance of sockeye salmon using tag information (Appendix 1.B).

Distribution of radiotagged sockeye salmon was described by mapping the final destination as determined from both ground-based receiver stations and aerial tracking. “Final destination” was defined as the farthest upstream location reported for a radiotagged fish within any tributary of the Kuskokwim River. In an attempt to best reflect the expected distribution of spawning sockeye salmon, only radiotagged fish tracked to a tributary stream were included in the final analysis. There is no evidence of sockeye salmon spawning in the mainstem Kuskokwim River. Tagged fish that were detected in the mainstem Kuskokwim River are believed to represent a combination of regurgitated tags and fish that expired prior to entering a tributary system. Fish that did not resume upstream migration (defined as passing the first upstream ground-based receiver station at Birch Tree Crossing, rkm 294; Figure 1.1) were also excluded in an effort to mitigate bias related to tagging and handling stress. The proportion of radiotagged sockeye salmon that returned to a particular tributary was calculated with adjustments to account for changes in the daily radiotagging rate and fishing effort (Wuttig and Evenson 2002). The weighted proportion for an individual spawning stock was calculated as:

$$\hat{P}^*{}_{Stock_i} = \frac{\sum_{i=1}^{n_t} w_i I(Stock_i)}{\sum_{i=1}^{n_t} wi} \qquad (1)$$

where:

$$w_i = \left(\frac{X_i}{h_i x_i}\right) \qquad (2)$$

$I(Stock_i)$ = 1 if fish i was assigned to stock i and 0 otherwise

X_i = the number of fish captured on day i;

x_i = the number of fish radiotagged on day i;

h_i = the hours of fishing effort on day i; and

n_t = the total number of radiotagged fish.

The variance and 95% confidence intervals of $\hat{P}^*{}_{Stock_i}$ were estimated using parameterized bootstrap techniques (Sokal and Rohlf 1995). Using Equation (1), 2,000 bootstrap estimates were computed after drawing samples of size equal to the number of radiotagged fish with replacement from the original data that was comprised of a list of fates of all the radiotagged fish. The sample variance of these bootstrap replicates was used to estimate Var($\hat{P}^*{}_{Stock_i}$). The 2.5 and 97.5 percentiles of the bootstrap distribution were used to estimate a 95% CI.

Stock-specific run timing at the tagging site were described through examination of the tagging date for each radiotagged salmon that successfully reached a spawning area (Mundy 1979; Merritt and Roberson 1986; Keefer et al. 2004). The median date of passage for each stock was calculated. Differences in run timing among major stocks were tested using Kolmogorov-Smirnov tests (Sokal and Rohlf 1995).

Stock-specific migration rates upstream of the tagging site were determined through examination of the number of days it took radiotagged fish to travel between the ground-based receiver station at Birch Tree Crossing and a ground-based receiver station near the mouth of one of three sub-basins including the Stony (and outlet of Telaquana Lake), Holitna (and Hoholitna and Kogrukluk), and Aniak rivers (Figure 1.1). Migration rate was defined as the average river kilometers per day between towers. Additionally, migration rates of radiotagged fish returning to the Holitna and Stony rivers were compared over a standardized section of the Kuskokwim River from the Birch Tree Crossing receiver station (rkm 294) to the Red Devil station (rkm 472). Differences were compared using t-tests (Sokal and Rohlf 1995).

RESULTS

TAGGING

The temporal distribution of deployed radio tags was a few days earlier than the overall sockeye salmon run timing, as estimated by catches in the fish wheels both in 2006 and 2007 (Figure 1.2). In 2006, 498 radio tags were deployed, the first on 14 June and the last on 15 August, with 50% deployed in fish captured on the north bank and 50% on the south bank. In 2007, 488 radio tags were deployed, the first on 21 June and the last on 14 August, with 48% deployed on the north bank and 50% on the south bank (2% had incomplete information records). The proportion of tags recovered by bank of capture was similar for all monitored stocks except the Aniak River. In 2006, 70% of fish tracked to the Aniak River were tagged on the south bank; and in 2007, 60% were tagged on the south bank.

Fates were described for all radiotagged fish (Table 1.1). In both 2006 and 2007, 3% of radiotagged fish either lost their tags or were never located after tagging. In 2006, 9% of radiotagged fish were detected downstream of the tagging site and did not resume upstream migration, compared to 15% in 2007. Among the successful upstream migrants (defined as migrating past the first upstream tracking station at Birch Tree Crossing), 88% were tracked to a spawning tributary in 2006, and 83% in 2007.

Age, sex, and length composition of the radiotagged fish was similar in 2006 and 2007 (Table 1.2). No 0-check fish were among those radiotagged in 2006, but four were found among the 2007 deployments (0-check fish undergo smoltification within a few months after emergence from the gravel, so their scales have no freshwater annulus or “check”).

DISTRIBUTION

Radiotagged sockeye salmon primarily traveled to tributaries within the middle Kuskokwim River basin (Figures 1.3, 1.4). Based on weighted distributions, Holitna River sub-basin accounted for the majority of the radiotagged fish in both years, followed by Stony River sub-basin and the Aniak River sub-basin (Tables 1.3, 1.4). Smaller numbers of fish were tracked to the Holokuk, Oskawalik, and George rivers. In 2006, one radiotagged fish was found in Vreeland Creek and one in Swift River drainage. No radiotagged sockeye salmon were found in the Kuskokwim River basin upstream of the Swift River drainage in either year.

The majority of radiotagged fish were located in areas of sub-basins without access to lakes. Within the Holitna River sub-basin, radiotagged fish were tracked to both the mainstem Holitna River and various tributaries (Tables 1.3, 1.4). The majority were tracked to the mainstem Holitna River, but a notable number of tagged fish were located in the larger tributaries, specifically the Hoholitna, Kogrukluk, and Chukowan rivers. No radiotagged fish entered Whitefish Lake at the headwaters of the Hoholitna River. Within the Stony River sub-basin, radiotagged fish were tracked to locations in either mainstem Stony River or one of two lake systems (Telaquana Lake and Two Lakes). Within the Aniak River sub-basin, radiotagged fish were found in both the mainstem Aniak River and various tributaries; however, the majority were tracked to the mainstem Aniak River downstream of the confluence with the Salmon and Kipchuk rivers. No radiotagged sockeye salmon were tracked to Aniak Lake.

STOCK-SPECIFIC RUN TIMING

The timing of stocks passing the Kalskag tagging site followed similar trends in 2006 and 2007 (Figure 1.5). The median date of passage for Stony River radiotagged fish was 3 July in 2006 and 2 July in 2007. The median date of passage for fish tracked to the Holitna River sub-basin was 5 July in 2006 and 7 July in 2007 and for fish tracked to the Aniak River the median dates of passage were 13 July in 2006 and 8 July in 2007. In 2006, there was a significant difference in run timing between fish tracked to the Stony and Aniak rivers ($D=0.339$, $P<0.01$) and between fish tracked to the Holitna and Aniak rivers ($D=0.250$, $P<0.05$), but not between fish tracked to the Stony and Holitna rivers ($D=0.178$, $P=0.075$). In 2007 there was a significant difference in run timing between fish tracked to the Stony and Aniak rivers ($D=0.539$, $P<0.001$) and between fish tracked to the Stony and Holitna rivers ($D=0.372$, $P<0.001$), but not between fish tracked to the Holitna and Aniak rivers ($D=0.167$, $P=0.478$).

STOCK-SPECIFIC MIGRATION RATES

Radiotagged sockeye salmon returning to the Holitna River basin generally traveled the fastest on average from the Birch Tree Crossing start point to the ground-based receiver in the lower Holitna River basin (Table 1.5; Appendix 1.C). Aniak River fish traveled slowest from the Birch Tree Crossing start point in both years. Radiotagged fish returning to the Stony River drainage traveled slower than Holitna River fish in both years. Though they had the longest migration distance, radiotagged fish returning to Telaquana Lake traveled slower than Holitna fish in both years. Travel rates indicate that radiotagged fish tended to travel faster in the mainstem Kuskokwim River than within tributaries.

Similar relationships were found for migration rates of Holitna River and Stony River fish from the Birch Tree Crossing tracking station to the Red Devil station. Over this stretch of mainstem, fish tracked to the Holitna River traveled at an average rate of 48.7 rkm/day in 2006, and 41.3 rkm/day in 2007, and Stony River fish traveled at 43.1 rkm/day and 40.8 rkm/day. There was a significant difference between migration rates in 2006 ($t=2.56$, $df=318$, $P<0.05$), but not 2007.

DISCUSSION

TAGGING

The number of radiotagged fish found downstream of the tagging site, and did not resume upstream migration after tagging, was less in 2006 than in 2007. In both years, similar efforts were made to reduce holding time to minimize stress on the fish. It is possible that different water conditions between the two years resulted in fish being less stressed in 2006 than in 2007. Temperatures have been shown to lead to increased pre-spawning loss and stress in the Fraser River (IPSFC 1976; Crossin et al. 2008), but average surface water temperatures at the Kuskokwim tagging site were nearly identical between the two years during June and early July. There was, however, lower water levels and increased water clarity in June and July of 2007 that may have increased stress (http://waterdata.usgs.gov/usa/nwis/nwisman/?site_no=15304000&agency_cd=USGS). Difference between the two years could also be due to variability in the effectiveness of the crew at successful implanting the radio transmitters.

DISTRIBUTION

Significance of Holitna River Drainage

The Holitna River drainage appears to be the primary destination of returning sockeye salmon in the Kuskokwim River, accounting for 71% and 70% of the weighted tributary tag distribution upstream of Kalskag in 2006 and 2007, respectively. Sockeye salmon occur in tributaries downstream of the study area (Tuluksak, Kisaralik-Kasigluk, Kwethluk, and Eek rivers), but abundance in each of these streams appears limited, ranging from few dozen to a few thousand fish based on weir counts in the Tuluksak and Kwethluk rivers (Molyneaux and Brannian 2006). The prominence of sockeye salmon in the Holitna River echoes similar findings for Chinook (Stuby 2007) and chum salmon (Bue et al. 2008), and highlights the importance of this sub-basin to overall salmon production in the Kuskokwim River.

The importance of the Holitna River to the overall Kuskokwim River sockeye salmon run supports the utility of managers using the Kogrukluk River weir, located in the upper Holitna River drainage, as an index site for monitoring sockeye salmon escapement. The Kogrukluk River accounted for 15 and 17% of the total distribution in this study, and has an average annual escapement of 12,744 sockeye salmon (range 1,670–60,807; Molyneaux and Brannian 2006). A minimum escapement goal of 2,000 sockeye salmon was established for the weir in 1983 (Buklis 1993), but the goal was discontinued in 1993. This decision was made under the assumption that sockeye salmon were incidental in the Kogrukluk River, and Holitna River generally, because of the lack of lake habitat in the drainage that is typically associated with sockeye salmon. So, the logic went, these drainages were assumed to not be representative of the bulk of Kuskokwim River sockeye salmon production (Burkey et al. 1999). In light of our findings, however, the Kogrukluk River may indeed be a reasonable index stream for monitoring sockeye salmon escapement, and in 2009 ADF&G re-established an escapement goal at the weir of 4,400–17,000 as part of a response to growing interest in developing a directed commercial sockeye salmon fishery (Volk et al. 2009).

Life History Strategies

Sockeye salmon are typically associated with rivers that provide access to lake habitat where juveniles rear for one to two years prior to smolting, such as those found in Bristol Bay (Burgner 1991). These are referred to as following a “lake ecotype” life history strategy (Wood et al. 2008). Likely lake-type populations within our study area include fish from the Stony and Holokuk rivers, which only accounted for 18 to 20% of radiotagged fish in 2006 and 2007. Downstream of our study area, lake-type populations have also been reported in the Kwethluk River (McPhee et al. 2009).

Tributaries with no associated lake system accounted for 81% and 78% of the total tributary tag distribution in our study area in 2006 and 2007, respectively, including fish from the Holitna, Aniak, Oskawalik, and George rivers. Sockeye salmon from these streams appear to follow the “river ecotype” life history strategy where following emergence juveniles rear and overwinter in river channel and slough habitats where water velocity is slow (Wood et al. 2008). River-type populations are not abundant across the Pacific Rim, though small populations are reported throughout much of the species range (e.g. Wood et al. 1987; Burgner 1991; Gustavson and Winans 1999; Eiler et al. 1992). A relatively large population of river-type sockeye salmon in the Kuskokwim River was unexpected because of the presence of predatory northern pike (*Esox lucius*) and sheefish (*Stenodus leucichthys*), and large populations of Chinook and coho (*O. kisutch*) salmon with piscivorous juvenile stages (Chapter 2 this document).

Some watersheds also produce 0-check or "sea ecotype" sockeye salmon that spend at most a few months after emergence in river habitats before smolting (Wood et al. 2008). Examples of watersheds with more prominent sea-type sockeye salmon include Harrison River (Fraser watershed), Stikine River, Puget Sound rivers, and Nushagak River (Schaefer 1951; Wood et al. 1987; Gustafson and Winans 1999; Westing et al. 2005). However, no 0-checked fish were among those radiotagged in the Kuskokwim River in 2006, and the incidence in 2007 was <1%. Similarly, 0-check sockeye salmon account for <1% of the historical commercial harvest in the Kuskokwim River (Molyneaux and Folletti 2005).

These three life history strategies likely reflect differences in productivity. This has been demonstrated by differences in sizes, ages, and fecundities of spawning adults (Rogers 1987; Blair et al. 1993), in high heterogeneity in sizes of riverine juveniles (Wood et al. 1987), and differences in genetic diversity and genetic structure (Beacham et al. 2004; Gustafson and Winans 1999; McPhee et al. 2009). Interestingly, there was a difference in the proportion of radiotagged sockeye salmon returning to the Stony River between 2006 and 2007, a trend not observed in any of the river-type populations. This could reflect different dynamics encountered by lake-type versus river-type life histories. River-type sockeye salmon may return to dynamic spawning areas more susceptible to changes in water level, freezing, dessication, or silt load, but may also be more able to move to more suitable spawning habitats. Lake-type populations may have more stable habitats in some years, but populations may be less able to adapt to changing environments. One life history type might be a greater producer under one climatic scheme, while the other could dominate under a different climatic regime. This biocomplexity is important for maintaining the resilience of the species under environmental change (Hilborn et al. 2003; Schindler et al. 2010). Genetic stock identification techniques applied to mixed-stock samples, such as commercial harvest, may prove to be a useful and cost effective tool for assessing short-term and long-term shifts between river-type and lake-type sockeye salmon in the Kuskokwim River.

Kuskokwim River salmon managers cannot necessarily apply knowledge gained elsewhere from lake-type sockeye salmon populations as they may not be truly representative of productivity. River-type populations may have higher volatility in their annual abundance compared to lake-type populations, probably associated with instability in their riverine spawning and rearing environments (McPhee et al. 2009). Consequently, a fishery reliant on river-type sockeye salmon should expect more variable annual harvest levels than occur in fisheries focused on lake-type fish. This high volatility is evident in the coefficient of variations (CVs) of annual sockeye salmon escapements at weir projects in the Kuskokwim River. Among example river-type populations, CVs include 1.17 at Takotna River, 0.95 at Tatlawiksuk River, 0.95 at Kogrukluk River, 0.89 at George River, and 0.89 at Tuluksak River. In comparison, the CV is only 0.62 in the Middle Fork Goodnews River and 0.67 in the Kanektok River where lake-type fish dominate. Interestingly, the CV for Kwethluk River abundance is 0.67, which may indicate that lake-type fish are more prevalent than river-type fish. These calculations were limited to escapements occurring between 2001 and 2008, when minimal commercial harvest occurred in the Kuskokwim River, and a relatively consistent harvest occurred in Kuskokwim Bay where Middle Fork Goodnews and Kanektok river fish are harvested. Given this volatility, and the limited capacity for real-time assessment of sockeye salmon abundance in the Kuskokwim River, an aggressive harvest strategy dependent on river-type sockeye salmon has a higher risk of overexploitation. The likely variability in productivity between river-type and lake-type populations requires monitoring escapements of both life history types.

Possible Colonization

No radiotagged fish traveled upstream of the Swift River drainage; however, occurrence of small numbers of sockeye salmon are documented in a few upper Kuskokwim River tributaries, notably the Takotna (Costello et al. 2008), Tatlawiksuk (Stewart et al. 2008), and South Fork Kuskokwim (Nick Alexia, resident, Nikolai, personal communication) rivers. In the Takotna River, which has annual escapement estimates since 2000, sockeye salmon passage has ranged from 0 to 60 fish. It is possible that these fish are strays from river-type Kuskokwim sockeye salmon stocks, considering Wood et al. (2008) argument that river-type sockeye salmon are more likely to stray from natal streams and colonize new habitats. Lake-type populations are less likely to stray, though this hypothesis has been challenged in at least some instances (e.g., Pavey et al. 2007). Studies suggest that riverine sockeye salmon may have been the primary colonists of new habitat following glaciation (Wood 1995). Also, genetics studies demonstrate less differentiation among river-type sockeye salmon populations compared to lake-type populations, implying that natal homing may be less precise in river-type populations (Gustafson and Winans 1999; Beacham et al. 2004). Recent studies confirm this relationship amongst some Kuskokwim River sockeye salmon populations (McPhee et al. 2009)

Stock-Specific Run Timing

There was broad overlap in run timings at the tagging site between Holitna, Stony, and Aniak River sockeye salmon stocks, which collectively comprise about 95% of the run. Consequently, it is unlikely that managers could time the harvest to target one of these major stocks over another. This same pattern of broad overlap in run timing is consistent with the pattern seen with anchor tags in 2002 through 2006 (Appendix 1.C; Schaberg et al. 2010).

Stock-specific run timing patterns may have limited management function for Kuskokwim River sockeye salmon, but studies focused on other species at times showed a wide divergence between stocks that does hold potential for management application, particularly for chum salmon (Schaberg et al. 2010). Regardless of species, in question is whether the stock-specific run timing patterns seen at the Kalskag tagging site (rkm 270) can be extrapolated downstream to District 1 (rkm 5 to 203) where most of the harvest occurs. There were practical reasons why tagging was done near Kalskag instead of in District 1, including concern for loss of expensive radio tags to District 1 harvest, and the need for adequate river current to operate fish wheels that allowed catching large numbers of fish for tagging. Still, to resolve the issue, concurrent tagging in District 1 and the Kalskag site should be conducted while the wide geographic array of tag recovery platforms (weirs) still exists. Such a study would also clarify how lower Kuskokwim River salmon stocks such as those in the Kwethluk and Tuluksak rivers place in the run timing patterns.

Stock-Specific Migration Rates

Average migration rates in the mainstem Kuskokwim River varied widely between stocks, ranging from about 9 to 30 rkm/day for Aniak and Holitna River sockeye salmon. Slower migrating stocks could be more susceptible to harvest because of their protracted exposure to the fishery. Results from this study indicate that while there may be some differences in migration rates between stocks, it is likely that the run timings of specific stocks overlap throughout the migration route. As with stock-specific run timing, it is unknown whether the stock-specific migration rates seen at the Kalskag tagging site (rkm 270) can be extrapolated downstream to District 1 (rkm 5–203). Again, concurrent tagging in District 1 and the Kalskag site would provide some resolution.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study should be taken in context, since the behavior and distribution of tagged fish may or may not be representative of untagged fish. It is possible that some stock selectivity existed in the design of this study, though there was no way to measure this bias with the existing platform. Efforts to recover anchortagged fish in 2006 allowed a means to test for potential biases in that year, and results suggest equal probability of capture between Telaquana Lake and Kogrukluk River weir capture sites (Appendix 1.B). These efforts lend support to the distributions seen here, but are only one year of limited diagnostics. Further study is necessary in order to assess the applicability of the results cited here, and caution should be used when interpreting these results.

However, this study was the first to document sockeye salmon distribution in the Kuskokwim River drainage. Several points were learned from this study that could be important for management:

1. Both river-type and lake-type sockeye salmon life history ecotypes are important contributors to the annual Kuskokwim River sockeye salmon run, though river-type may be the more dominant.
2. The Holitna River basin had the single largest concentration of radiotagged sockeye salmon in the Kuskokwim River, with the Stony and Aniak River basins being the second and third largest concentrations, respectively.
3. Stock-specific run timing and migration rates at Kalskag show broad overlap between stocks.
4. The Kogrukluk River weir provides a reasonable index for monitoring sockeye salmon escapement to the Kuskokwim River. Long-term operations of this weir are necessary to assess the adequacy of the escapement within the context of the escapement goal range of 4,400–17,000 sockeye salmon, established in 2009.
5. Future measures should include establishing an escapement monitoring program representative of the diversity found within Kuskokwim River sockeye salmon. Establishing such a platform would also provide the means to develop a total abundance estimate that will be needed to address issues of harvestable surplus, exploitation rate, and annual variability in stock composition. In addition, this platform would be necessary for the diagnostics necessary for mark–recapture models and to verify the validity of the distributions presented in this study.

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REFERENCES CITED

Beacham, T. D., B. McIntosh, and C. MacConnachie. 2004. Population structure of lake-type and river-type sockeye salmon in transboundary rivers of northern British Columbia, Canadain Journal of Fisheries Biology 65:389–402.

Bergstrom, D. J., and C. Whitmore. 2004. Kuskokwim River Chinook and chum salmon stock status and action plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A04-02, Anchorage.

Blair, G. R., Rogers, D. E., and Quinn, T. P. 1993. Variation in life history characteristics and morphology of sockeye salmon in the Kvichak River system, Bristol Bay, Alaska. Transactions of the American Fisheries Society 122:550–559.

Bue, B. G., D. B. Molyneaux, and K. L. Schaberg. 2008. Kuskokwim River chum salmon run reconstruction. Alaska Department of Fish and Game, Fishery Data Series No. 08-64, Anchorage.

Buklis, L. S. 1993. Documentation of Arctic-Yukon-Kuskokwim region salmon escapement goals in effect as of the 1992 fishing season. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A93-03, Anchorage.

Burger, C. V., J. E. Finn, and L. Holland-Bartels. 1995. Pattern of shoreline spawning by sockeye salmon in a glacially turbid lake: evidence for subpopulation differentiation. Transactions of the American Fisheries Society 124:1–15.

Burgner, R. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). [*in*] Pacific Salmon Life Histories. C. Groot and L. Margolis, editors. Vancouver: UBC Press, pp. 1-117.

Burkey, Jr. C., and P. Salomone. 1999. Kuskokwim Area salmon escapement observation catalog, 1984-1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A99-11, Anchorage.

Burkey, Jr. C., M. Coffing, J. Menard, D.B. Molyneaux, C. Utermohle, and T. Vania. 1999. Annual management report for the subsistence and commercial fisheries of the Kuskokwim Area 1997. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 3A99-12, Anchorage.

Costello, D. J., D. B. Molyneaux, and C. Goods. 2008. Takotna River salmon studies, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 08-38, Anchorage.

Crossin, G. T., S. G. Hinch, S. J. Cooke, D. W. Welch, D. A. Patterson, S. R. M. Jones, A. G. Lotto, R. A. Leggatt, M. T. Mathes, J. M. Shrimpton, G. Van Der Kraak, and A. P. Farrell. 2008. Exposure to high temperature influences the behaviour, physiology, and survival of sockeye salmon during spawning migration. Canadian Journal of Zoology 86:127–140.

Devries, D. R. and R. V. Frie. 1996. Determination of age and growth. [*in*] Fisheries Techniques*.* B. Murphy and D. Willis, editors. Bethesda: American Fisheries Society, pp. 483-513.

Eiler, J. H. 1995. A remote satellite-linked tracking system for studying Pacific salmon with radiotelemetry. Trans. Am. Fish. Soc. 124: 184-193.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Transactions of the American Fisheries Society 121:701–708.

Gustavson, R. G., and G. A. Winans. 1999. Distribution and population genetic structure of river- and sea-type sockeye salmon in western North America. Ecology of Freshwater Fish 8:181–193.

Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 1996. Tagging and marking. [*in*] Fisheries Techniques. B. Murphy and D. Willis, editors. Bethesda: American Fisheries Society, pp. 353-384.

Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences 100(11):6564–6568.

IPSFC (International Pacific Salmon Fisheries Commission). 1976. Annual report for the year 1975. International Pacific Salmon Fisheries Commission, New Westminster, BC. 53 pp.

REFERENCES CITED (Continued)

Keefer, M. L., C. A. Peery, M. A. Jepson, K. R. Tolotti, and T. C. Bjornn. 2004. Stock-specific migration timing of adult spring-summer Chinook salmon in the Columbia River Basin. North American Journal of Fisheries Management 24:1145–1162.

Kerkvliet C. M., T. Hamazaki, K. E. Hyer, D. Cannon. 2003. A mark–recapture experiment to estimate the abundance of Kuskokwim River sockeye, chum, and coho salmon, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A03-25, Anchorage.

Kerkvliet, C. M., and T. Hamazaki. 2002. A mark–recapture experiment to estimate abundance of Kuskokwim River coho salmon, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A02-15, Anchorage.

Liller, Z. W., D. J. Costello, and D. B. Molyneaux. 2008. Kogrukluk River weir salmon studies, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 08-26, Anchorage.

McPhee, M. V., T. H. Tappenbeck, D. C. Whited, and J. A. Stanford. 2009. Genetic diversity and population structure in the Kuskokwim River drainage support the recurrent evolution hypothesis for sockeye salmon life histories. Transactions of American Fisheries Society 138:1481–1489.

Merritt, M. F., and K. Roberson. 1986. Migratory timing of upper Copper River sockeye salmon stocks and its implications for the regulation of the commercial fishery. North American Journal of Fisheries Management 6:216–225.

Miller, S. J., K. C. Harper, and C. Whaley. 2008. Abundance and run timing of adult Pacific salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2007. Alaska Fisheries Data Series Number 2008-18, Kenai, Alaska.

Miller, S. J., K. C. Harper, and D. G. Spencer. 2007. Abundance and run timing of adult Pacific salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2006. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Number 2007-9, Kenai, Alaska.

Molyneaux, D. B., and D. L. Folletti. 2005. Salmon age, sex, and length catalog for the Kuskokwim Area, 2004. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A05-063, Anchorage.

Molyneaux, D. B., and L. K. Brannian. 2006. Review of escapement and abundance information for Kuskokwim area salmon stocks. Alaska Departmetn fo Fish and Game, Fishery Manuscript No. 06-08, Anchorage.

Mosher, K. H. 1969. Identification of Pacific salmon and steelhead trout by scale characteristics. USDOI, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, XF WC-A 317 1-17 (1969).

Mundy, P. 1979. Quantitative measure of migratory timing illustrated by application to the management of commercial salmon fisheries. Doctoral dissertation. University of Washington, Seattle.

Pavey, S. A., T. P. Hamon, J. L. Nielsen. 2007 Revisiting evolutionary dead ends in sockeye salmon (*Oncorhynchus nerka*) life history. CJFAS 64:1199-1208.

Pawluk, J., C. M. Kerkvliet, T. Hamazaki, K. E. Hyer, and D. Cannon. 2006a. A mark–recapture study of Kuskokwim River sockeye, chum, and coho salmon, 2004. Alaska Department of Fish and Game, Fishery Data Series No. 06-52, Anchorage.

Pawluk, J., J. Baumer, T. Hamazaki, and D. Orabutt. 2006b. A mark–recapture study of Kuskokwim River Chinook, sockeye, chum and coho salmon, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 06-54, Anchorage.

Policansky, D., and J. J. Magnuson. 1998. Genetics, metapopulations, and ecosystem management of fisheries. Ecological App. 8(1)(Supplement):119-123.

Rogers, D. E. 1987. The regulation of age at maturity in Wood River sockeye salmon (*Oncorhynchus nerka*). Canadian Special Publication of Fisheries and Aquatic Sciences No. 96:78–89.

REFERENCES CITED (Continued)

Schaberg, K. L., Z. W. Liller, and D. B. Molyneaux. 2010. A mark–recapture study of Kuskokwim River coho, chum, sockeye, and Chinook Salmon, 2001–2006. Alaska Department of Fish and Game, Fishery Data Series No. 10-32. Anchorage.

Schaefer, M. B. 1951. A study of the spawning populations of sockeye salmon in the Harrison River system: with special reference to the problem of enumeration by means of marked members. International Pacific Salmon Fisheries Commission Bulletin 4:205-207.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609–612.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research, third edition. New York: W.H. Freeman and Company, 887 pp.

Stewart R., D. J. Costello, D. B. Molyneaux, and J. M. Thalhauser. 2008. Tatlawiksuk River salmon studies, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 08-59, Anchorage.

Stuby, L. 2007. Inriver abundance of Chinook salmon in the Kuskokwim River, 2002-2006. Alaska Department of Fish and Game, Fishery Data Series No. 07-93, Anchorage.

Volk, E. C., M. J. Evenson, and R. H. Clark. 2009. Escapement goal recommendations for select Arctic-Yukon-Kuskokwim region salmon stocks, 2010. Alaska Department of Fish and Game, Fishery Manuscript No 09-07, Anchorage.

Westing C., S. Morstad, K. A. Weiland, T. Sands, L. Fair, F. West, and C. Brazil. 2005. Annual management report 2004 Bristol Bay Area. Alaska Department of Fish and Game, Fishery Management Report No. 05-41, Anchorage.

Whitmore, C., M. Martz, J. C. Linderman Jr., R. L. Fisher, and D. G. Bue. 2008. Annual management report for the subsistence and commercial fisheries of the Kuskokwim area, 2004. Alaska Department of Fish and Game, Fisheries Management Report No. 08-25, Anchorage.

Wood, C. C. 1995. Life history variation and population structure in sockeye salmon. American Fisheries Society Symp. 17:195–216.

Wood, C. C., B. E. Riddell, and D. T. Rutherford. 1987. Alternative life histories of sockeye salmon and their contribution to production in the Stikine River, Northern British Columbia. Canadian Special Publication of Fisheries and Aquatic Sciences 96:12–24.

Wood, C. C., J. W. Bickham, R. J. Nelson, C. J. Foote, and J. C. Patton. 2008. Recurrent evolution of life history ecotypes in sockeye salmon: implications for conservation and future evolution. Evolutionary Applications 1:207–221.

Wuttig, K. G., and M. J. Evenson. 2002. Assessment of Chinook, chum, and coho salmon escapements in the Holitna River drainage using radiotelemetry, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 02-05, Anchorage.

TABLES AND FIGURES

Table 1.1.–Fates of Kuskokwim River sockeye salmon radiotagged at the Kalskag Fish Wheels in 2006 and 2007.

Fate	Description	Number of tagged sockeye 2006	Number of tagged sockeye 2007	Percent of tagged sockeye 2006	Percent of tagged sockeye 2007
Not Detected	A fish that was never recorded swimming upstream past the Birch Tree Crossing tracking site (rkm 294).	17	17	3	3
Downstream	A fish that was detected downstream of the Kalskag tagging site that did not resume upstream migration.	44	71	9	15
Upstream Migrant	A fish that migrated upstream past the Birch Tree Crossing tracking site (rkm 294).	437	400	88	82
Tributary Spawner	A fish that entered a spawning tributary of the Kuskokwim River.	383	333	77	68
Subsistence Mortality	A fish that was reported as harvested by subsistence fishers.	3	3	1	1
	Total Deployed	498	488		

Table 1.2.–Age and sex composition of radiotagged sockeye salmon in 2006 and 2007.

Age	2006								2007							
	Females		Males		Unknown		Total		Females		Males		Unknown		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
0.3	0	0.0	0	0.0	0	-	0	0.0	2	1.1	2	0.8	0	0.0	4	0.9
1.2	22	12.0	16	6.4	0	-	38	8.8	22	12.5	44	18.0	1	50.0	67	15.9
1.3	137	74.5	206	82.7	0	-	343	79.2	133	75.6	169	69.3	1	50.0	303	71.8
1.4	16	8.7	15	6.0	0	-	31	7.2	9	5.1	16	6.6	0	0.0	25	5.9
2.2	0	0.0	3	1.2	0	-	3	0.7	1	0.6	0	0.0	0	0.0	1	0.2
2.3	9	4.9	7	2.8	0	-	16	3.7	9	5.1	13	5.3	0	0.0	22	5.2
2.4	0	0.0	2	0.8	0	-	2	0.5	0	0.0	0	0.0	0	0.0	0	0.0
ND	18		44		3		65		17		47		2		66	
Total Aged	184		249	50	0	0	433		176		244		2		422	
Total Sampled	202	40.6	293	58.8	3	0.6	498		193	39.5	291	59.6	4	0.8	488	

Note: Percentage by age is based on the number of aged scales. Percent by sex is based on total number of sockeye salmon sampled.

Table 1.3.–Distribution of radiotagged sockeye salmon in spawning tributaries of the Kuskokwim River in 2006, with adjustment to account for differences in daily tagging rates and fishing efforts.

Spawning Stream		Number of radio tags		Proportion of all radio tags[a]		Percentile Limits (5^{th} - 95^{th})	
Tributary	Sub-basin	Tributary	Sub-basin	Tributary	Sub-basin	Tributary	Sub-basin
Aniak - ALL		36		0.09		(0.01, 0.18)	
	Mainstem		21		0.06		(0.00, 0.13)
	Kipchuk		4		0.01		(0.00, 0.02)
	Upper Aniak		11		0.03		(0.00, 0.07)
Holokuk		12		0.03		(0.00, 0.10)	
Oskawalik		5		0.01		(0.00, 0.03)	
George		2		0.00		(0.00. 0.00)	
Holitna - ALL		264		0.71		(0.21, 1.00)	
	Mainstem		118		0.34		(0.07, 0.60)
	Hoholitna		54		0.15		(0.02, 0.29)
	Chukowan		27		0.07		(0.00, 0.16)
	Kogrukluk		61		0.15		(0.01, 0.28)
	Other		4		0.01		(0.00, 0.04)
Stony - ALL		62		0.15		(0.00, 0.32)	
	Mainstem		21		0.05		(0.00, 0.13)
	Telaquana		23		0.06		(0.00, 0.15)
	Two Lakes		18		0.03		(0.00, 0.08)
Other		2		0.01		(0.00, 0.01)	
TOTAL		383		1.00			

[a] Adjusted for daily tagging rates and fishing effort.

Table 1.4.–Distribution of radiotagged sockeye salmon in spawning tributaries of the Kuskokwim River in 2007, with adjustment to account for differences in daily tagging rates and fishing efforts.

Spawning Stream		Number of radio tags		Proportion of all radio tags[a]		Percentile Limits (5^{th} - 95^{th})	
Tributary	Sub-basin	Tributary	Sub-basin	Tributary	Sub-basin	Tributary	Sub-basin
Aniak - ALL		27		0.08		(0.04, 0.13)	
	Mainstem		14		0.04		(0.02, 0.06)
	Kipchuk		4		0.01		(0.00, 0.02)
	Upper Aniak		9		0.03		(0.00, 0.06)
Holokuk		7		0.01		(0.00, 0.03)	
Oskawalik		1		0.00		(0.00, 0.01)	
George		1		0.00		(0.00, 0.00)	
Holitna - ALL		222		0.70		(0.41, 1.00)	
	Mainstem		81		0.25		(0.15, 0.36)
	Hoholitna		63		0.21		(0.11, 0.30)
	Chukowan		24		0.06		(0.03, 0.10)
	Kogrukluk		53		0.17		(0.07, 0.28)
	Other		2		0.01		(0.00, 0.02)
Stony - ALL		75		0.19		(0.11, 0.27)	
	Mainstem		29		0.05		(0.02, 0.08)
	Telaquana		18		0.06		(0.02, 0.09)
	Two Lakes		28		0.08		(0.04, 0.13)
Other		0		0.00		(0.00, 0.00)	
TOTAL		333		1.00			

[a] Adjusted for daily tagging rates and fishing effort.

Table 1.5.–Migration rates (rkm/day) of radiotagged sockeye salmon in 2006 and 2007, based on ground-based tracking stations.

		2006			2007		
Tracking Station	Distance from Birch Tree Crossing tracking station (rkm)	Mean	95% CI	N	Mean	95% CI	N
Aniak River	29	6.7	0.9	36	5.2	0.9	27
Holitna River	204	27.4	0.9	264	23.6	0.8	222
Hoholitna River	252	28.0	2.2	54	25.0	1.4	63
Kogrukluk River	416	22.0	1.7	61	19.5	1.4	53
Stony River	249	21.2	1.4	62	20.5	1.4	75
Telaquana Lake	462	17.7	2.1	21	19.4	1.8	18

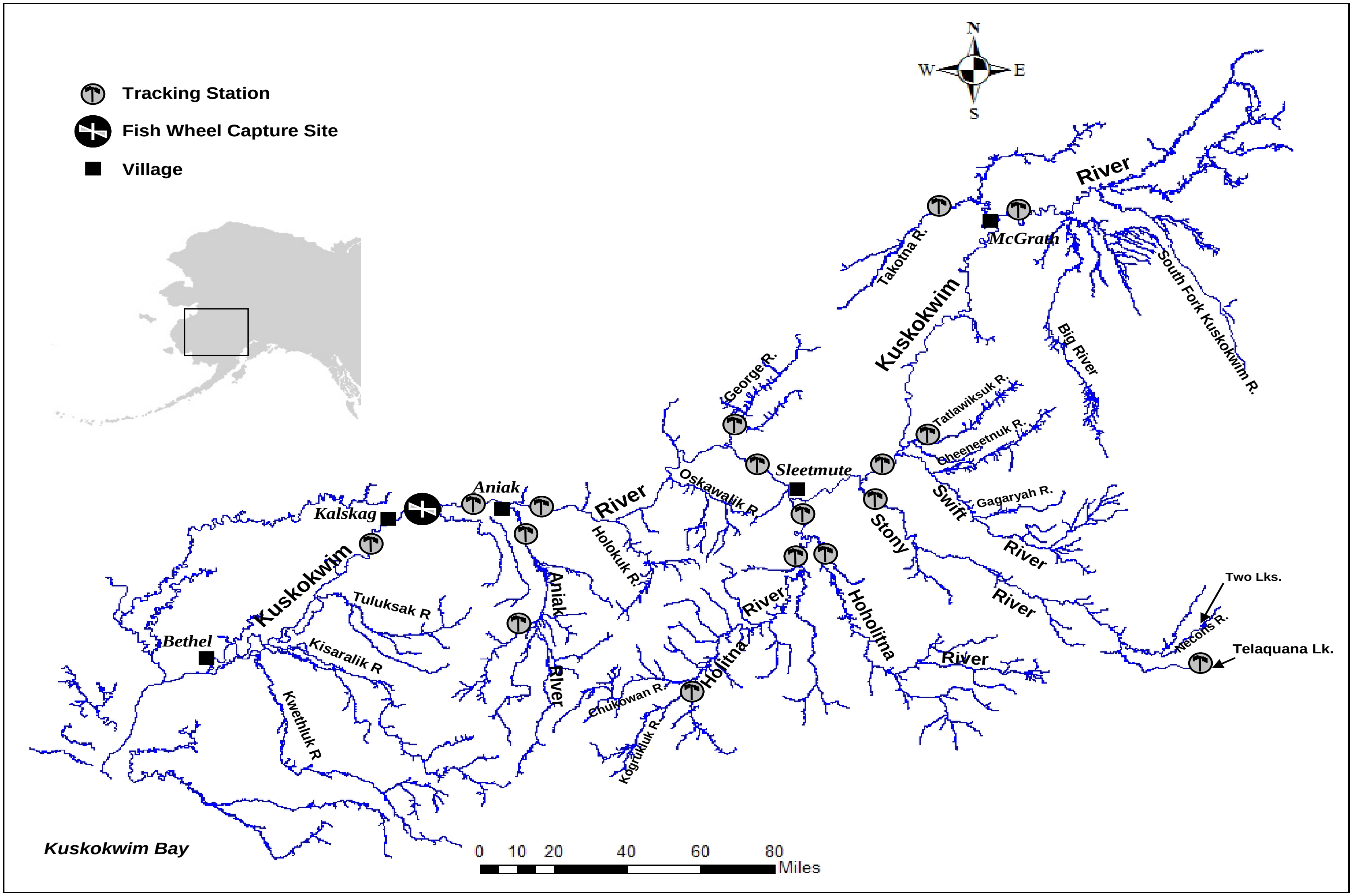

Figure 1.1.–Map of the Kuskokwim River showing tributaries, capture sites, and ground-based tracking stations.

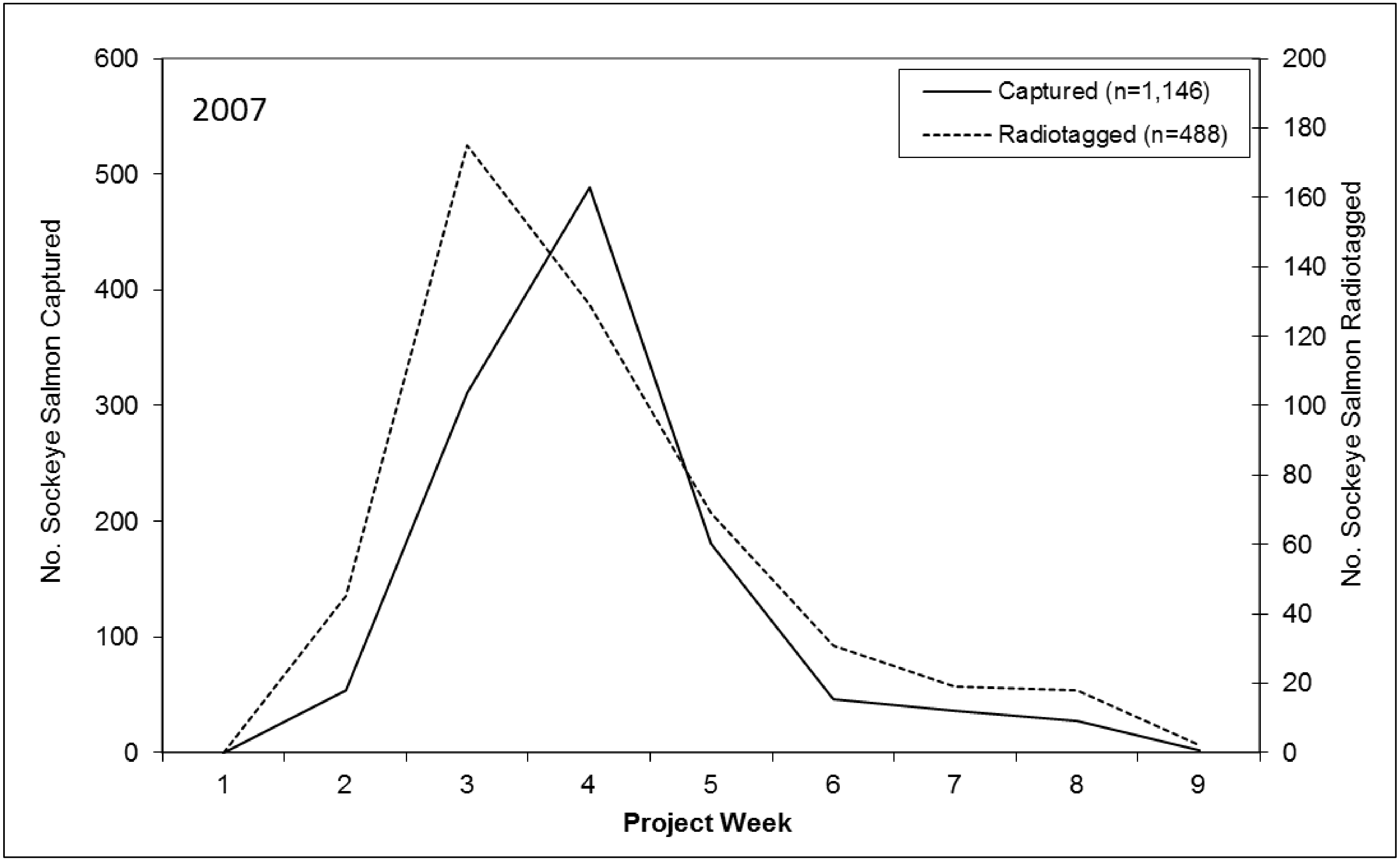

Figure 1.2.–Number of sockeye salmon captured and radiotagged by project week in 2006 and 2007.

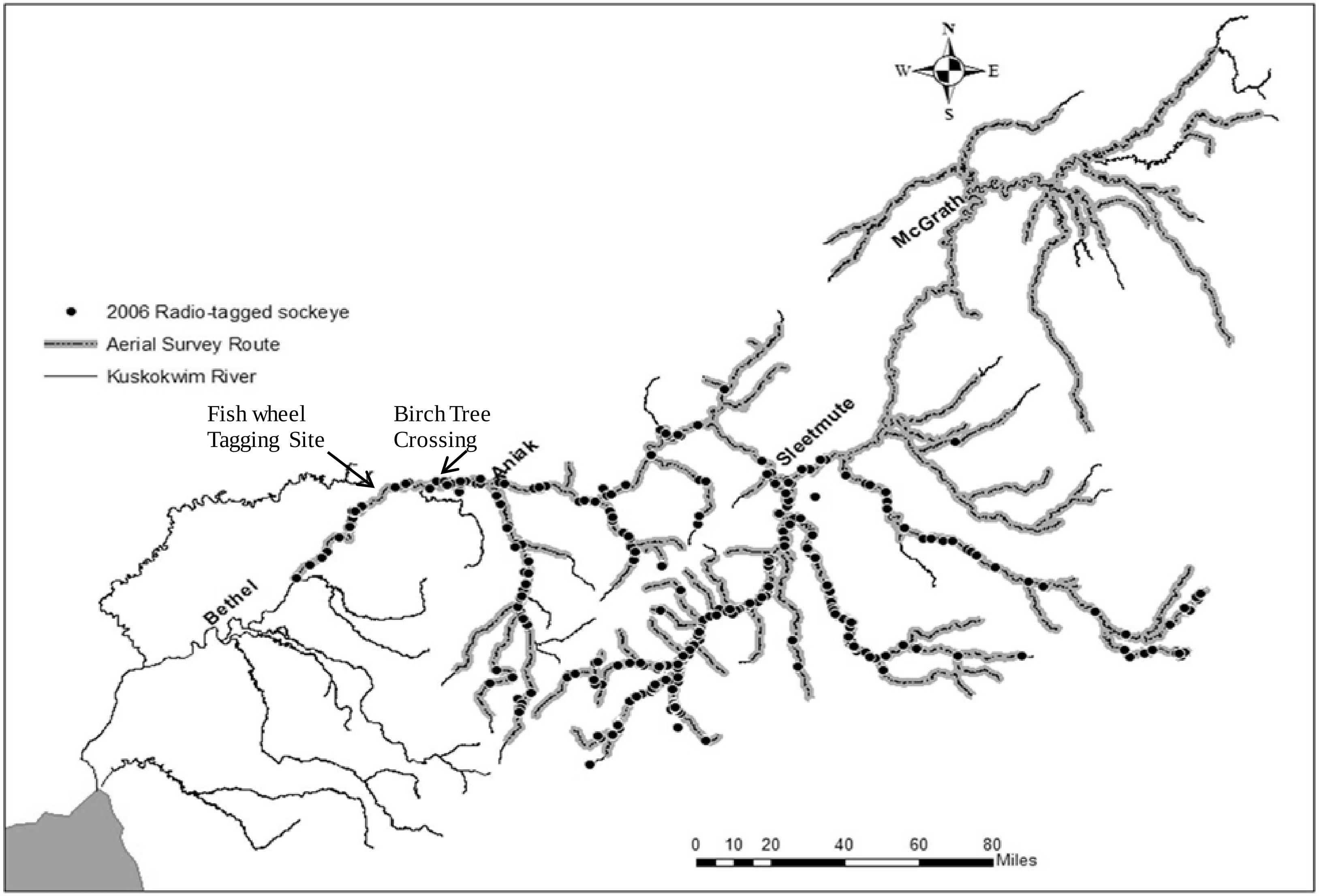

Figure 1.3.–Kuskokwim River drainage with aerial tracking coverage and uppermost locations of radiotagged sockeye salmon in 2006.

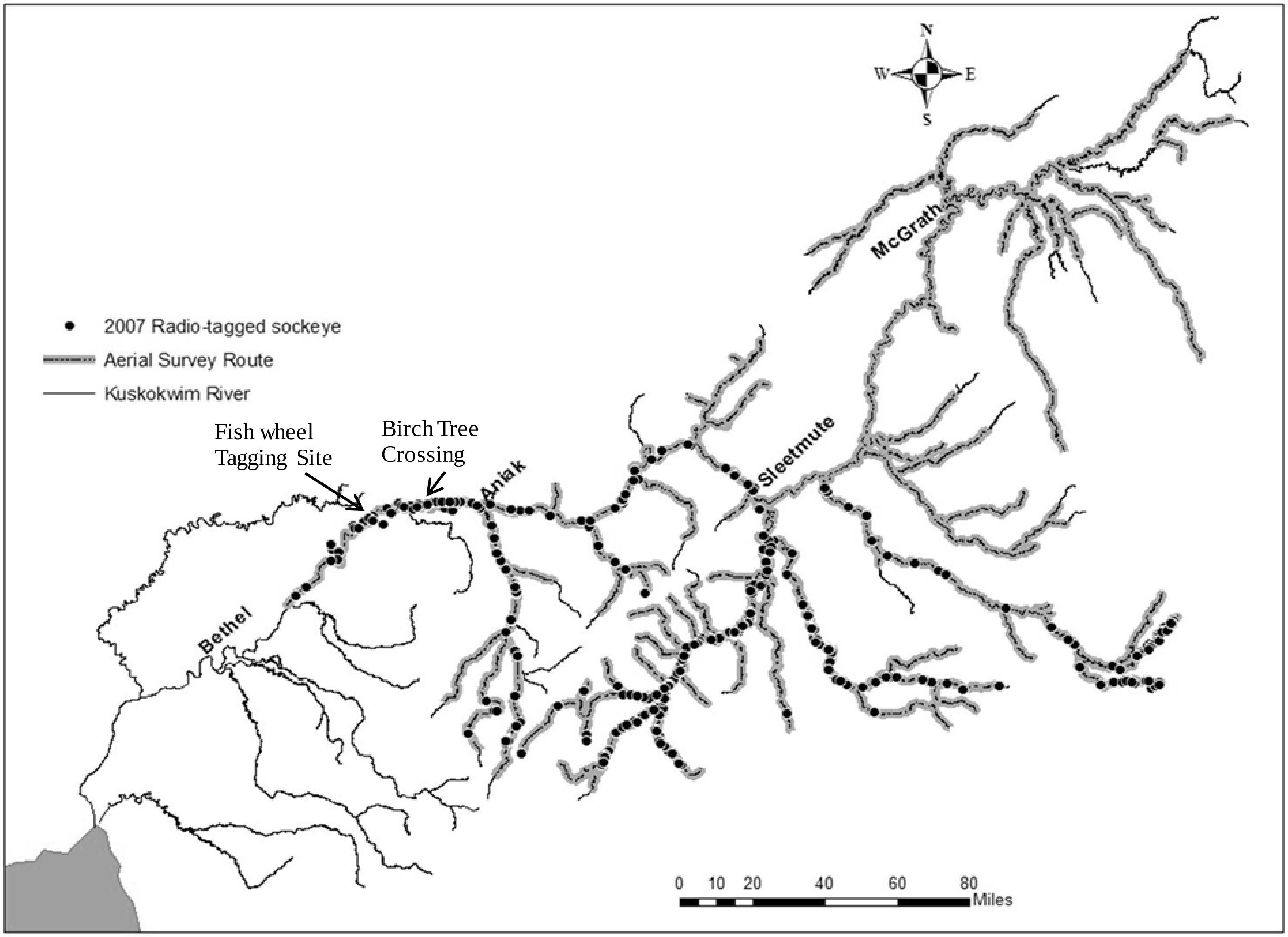

Figure 1.4.–Kuskokwim River drainage with aerial tracking coverage and uppermost locations of radiotagged sockeye salmon in 2007.

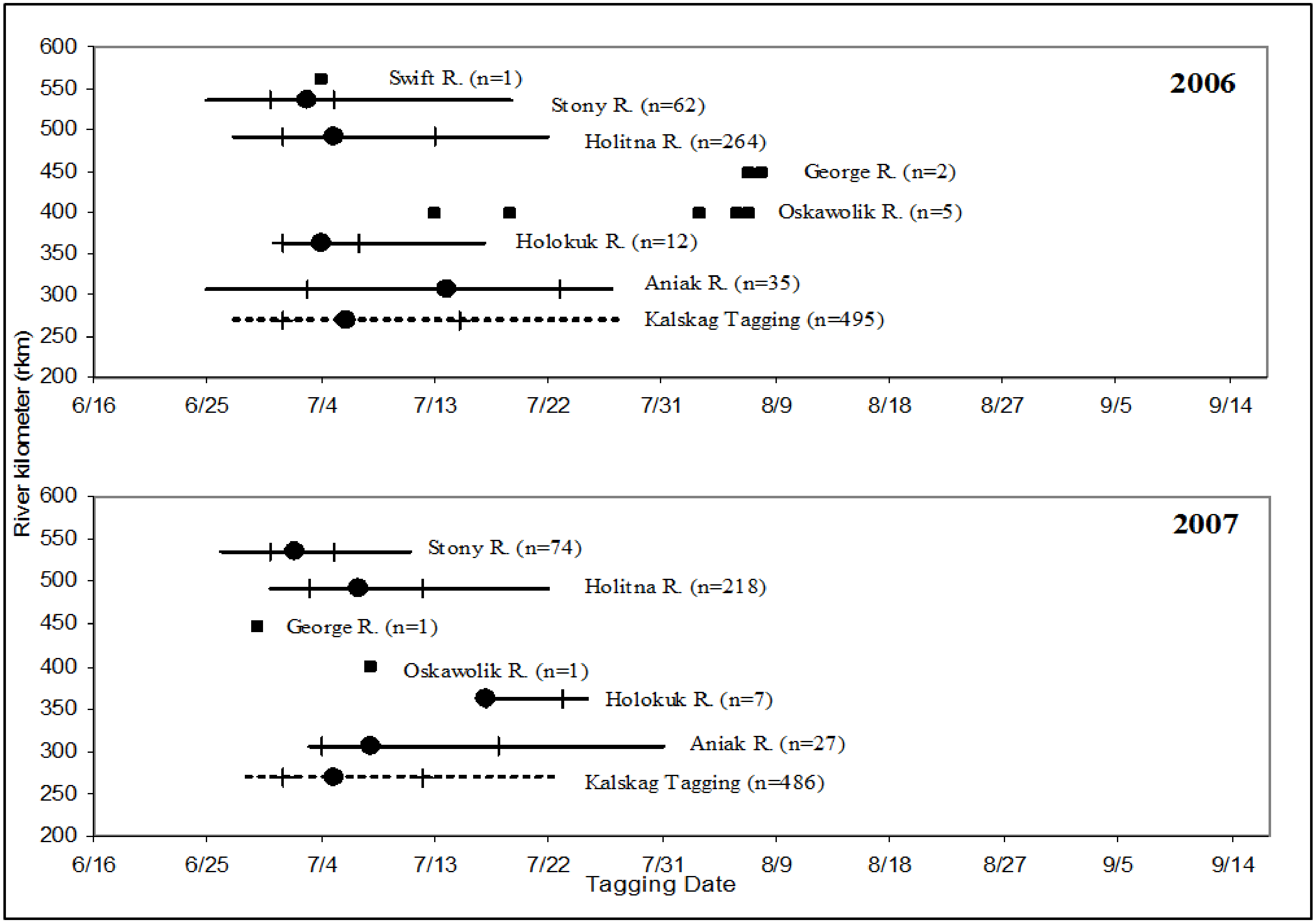

Figure 1.5.–Stock-specific run timing for sockeye salmon radiotagged in 2006 and 2007, including median (circle), quartile (vertical lines), and 10th and 90th percentile dates (horizontal line). Squares are tagging date for individual fish in tributaries with <5 recovered tags.

APPENDIX 1.A: 2005 PILOT RADIOTAGGING STUDY

Introduction

A pilot radiotelemetry project was conducted on Kuskokwim River sockeye salmon in 2005, as a precursor to the 2006–2007 efforts. Using funds provided by Coastal Villages Region Fund, National Park Service, and ADF&G, we purchased radio tags and tower supplies to study the feasibility of a full-scale radiotelemetry project. Results included some unexpected insights that were important in designing the 2006–2007 investigation.

Objectives:

1. Investigate geographic distribution of sockeye salmon spawning areas within the Kuskokwim River drainage upstream of Kalskag,
2. Investigate stock-specific run timing of adult sockeye salmon as they pass upstream of the Kalskag tagging site,
3. Identify and address potential difficulties associated with basinwide sockeye salmon radiotelemetry, and
4. Provide sockeye salmon tissue samples to identify discreet spawning populations through genetic analysis.

Methods

Capture and Tagging

Adult sockeye salmon returning to the Kuskokwim River in 2005 were captured with fish wheels at sites near the village of Upper Kalskag (Figure A1.1). Tags were deployed from 24 June to 1 July in order to correspond with the peak of sockeye salmon passage. The tagging event was partitioned into three tagging periods (Table A1.1). Efforts during the first period focused on evaluating the effects of tag size and holding time. During the second and third periods holding time was held to less than one hour to minimize tagging effects on fish behavior.

Fish were tagged with pulse-coded esophageal radio transmitters manufactured by Advanced Telemetry Systems (Isanti, Minnesota). Three tag models were used to evaluate effects of tag size: model F1835 (17 x 42 mm), model F1840 (17 x 51 mm), and model F1845 (19 x 51 mm). The size of the tag varied according to battery size, with a larger battery expected to result in a longer tag life. To best evaluate the effects of tag sizes, smaller fish (<550 mm MEF length) were initially targeted to be tagged with model F1845 tags and larger fish (>600 mm MEF length) were targeted to be tagged with model F1835 tags. Tagging was conducted without the use of anesthesia. Fish that were obviously injured or appeared stressed were not radiotagged. Transmitters were individually distinguishable by a unique encoded pulse pattern and frequency. Two frequencies with 50 encoded pulse patterns per frequency were used for a total of 100 uniquely identifiable tags.

All radiotagged fish were given a secondary mark of a uniquely numbered white spaghetti tag inserted near the dorsal fin (Guy et al. 1996). Information on sex, mideye to fork of tail (MEF) length, and hold time were recorded. Three scales were removed from the preferred region for age analyses (Devries and Frie 1996). A tissue sample from the axillary process was taken for future genetic stock identification analyses.

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Radiotagged sockeye salmon were tracked using a network of ground-based tracking stations being used for a concurrent Chinook salmon radiotelemetry studies (Figure A1.1; Stuby 2005). Three additional tracking stations were used in 2005 to address sockeye salmon-specific information needs: 1) mainstem Kuskokwim River upstream of Stony River, 2) lower Stony River drainage, and 3) downstream of Telaquana Lake. The ground-based stations consisted of several integrated components similar to Eiler (1995). Tracking stations recorded the date and times the fish were present, signal strength, activity (active or inactive), and location of the fish relative to the station (upriver or downriver). The data was periodically downloaded to a laptop computer, or transmitted to a NOAA geostationary operational environmental satellite (GOES) and downloaded via the internet.

Tracking and Tag Recovery

Aerial tracking surveys were conducted in July, August, and September along the mainstem Kuskokwim River and in major tributaries to identify and locate the fate of radiotagged fish. Survey periods bracketed the period when most sockeye salmon were likely to be on the spawning grounds. Tracking surveys were conducted in one plane with one observer (plus the pilot).

Boat tracking surveys were conducted periodically near the tagging sites to monitor for tags that had been regurgitated. Results from radiotelemetry studies on the Copper River suggested that most fish that expelled tags did so immediately after release (Evenson and Wuttig 2000). Extensive boat tracking was also conducted in Telaquana Lake from July to October to document movement of tagged sockeye salmon in the lake.

Radio tags were recovered opportunistically from fish captured in subsistence fisheries. To encourage voluntary tag recoveries, ADF&G conducted a postseason lottery. Each tag was printed with a toll-free number and mailing address for reporting tag recoveries and for entry into the lottery.

Results and Discussion

Of one hundred sockeye salmon radiotagged in 2005, seventy fish were radiotagged from 24 June to 1 July, nineteen were tagged from 12 to 14 July, and the remaining eleven were tagged on 21 and 22 July (Table A1.1). Deployment included fifty three fish captured on the north bank, thirty nine on the south bank, and eight fish were caught in gillnets. One tagged fish was recaptured at the tagging site, and the radio tag was removed and redeployed in another fish. All model F1835 and F1845 radio tags were deployed during the first tagging period.

Hold Time

Holding time appeared to have an effect on upstream migration. Of ninety two sockeye salmon captured and radiotagged from fish wheels, eight were tagged immediately upon capture, eighteen were held in live boxes <1 hour, twenty six were held >1–2 hours, fifteen were held >2–4 hours, eighteen were held >4–6 hours, and seven may have been held >6 hours. The exact holding time of each fish was unknown, still there appeared to be a holding time effect on upstream migration among our six bins (Figure A1.2).

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Future investigators need to consider this tagging effect in their study design and strive to minimize holding time. Other tagging studies have shown a similar effect on migration speed in sockeye salmon captured with fish wheels (J. Eiler, NOAA/NMFS, personal communication), and recommend short hold times to decrease delays in upstream migration.

Tag Size

Forty model F1845 tags (19 x 51 mm) were deployed, and use of this model was limited to the first tagging period of 24 June to 1 July. Tagged fish ranged between 510 and 610 mm MEF length (average 559 mm). Initially, smaller fish (<550 mm) were included, but the preferred size was increased after crew reported tight insertions that may result in a high risk of stomach rupture in fish <550 mm. Thirty-eight fish (95%) successfully continued their upstream migration. Two fish (5%) in the 550–610 mm length range were detected downstream of the tagging site and did not resume upstream migration. Taggers reported tight insertions of F1845 tags in fish smaller than about 560 mm.

Fifty model F1840 tags (17 x 51 mm) tags were deployed across all three tagging periods. Tagged fish ranged between 415 and 660 mm MEF length (average 554 mm). Forty-one fish (82%) successfully continued their upstream migration. Nine fish (18%) ranging in length between 450 and 570 mm (average length 523 mm) did not resume upstream migration. Crew reported tight insertions of F1840 tags in some fish smaller than about 450 mm MEF length.

Ten model F1835 (17 x 42 mm) tags were deployed, and use of this model was limited to the first tagging period of 24 June to 1 July. Larger fish were targeted with fish ranging between 570 and 625 mm MEF length (average 605 mm). Nine fish (90%) successfully continued their upstream migration, and one fish (10%) measuring 595 mm did not. Crew did not report any difficulties such as tight insertions with the F1835 radio tags.

Of the 3 tags tested, model F1840 gave the best combination of expected tag life and small tag size, and was suitable for the range of fish sizes encountered. The F1845 tag has the largest battery and longest tag life, but use risks stomach rupture in fish <550 mm MEF length. Sockeye salmon <550 mm accounted for 49.2% and 32.7% of sockeye salmon captured in these fish wheels during 2002 and 2003, so model F1845 is not well suited for any future tagging efforts. Although tight insertions that could result in stomach rupture were reported for the F1840 tags in fish <450 mm, crew reported that with care, they could successfully insert this model of tag in sockeye salmon as small as 400 mm MEF. Based on length data from 2002 and 2003, fish <400 mm constituted only 3.9% and 6.4%, of the catch at the Kalskag and Aniak fish wheels. Though the F1835 tag gives the best option for tagging fish <400 mm, it has the smallest battery and thus the shortest tag life of the tags considered, so is less desirable because of concern that tags deployed early in the season may not remain active through the final tracking in September or October.

Distribution

Of the eighty four radiotagged sockeye salmon that successfully resumed upstream migration and entered tributary streams, eleven returned to the Aniak River, one returned to the Holokuk River, fifty one returned to the Holitna River, twenty returned to the Stony River, and one returned to the Swift River (Figure A1.3). Four tagged fish were last detected in the mainstem

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Kuskokwim River; it is unknown if these fish spawned or died in these areas or if the tags were expelled. Five fish passed downstream of the tracking station located downstream of the tagging site, and they did not resume upstream migration. The remaining 7 fish were not detected after tagging and had unknown fates.

Many of the sockeye salmon tagged in this feasibility study traveled to, and presumably spawned in, tributaries not associated with lake habitat. Only fish that traveled to the Aniak and Stony rivers have access to substantial lake habitat for juvenile rearing typical to other systems (e.g., Bristol Bay; Burgner 1991). This was unexpected in part because since 1984 commercial catch sampling shows that approximately 80% of returning adult sockeye salmon spend one winter in freshwater as juveniles before migrating to sea (Molyneaux and Folletti 2005), and the assumption was that this winter was spent in a lake (e.g., "lake-type" sockeye salmon). Progeny of most of the sockeye salmon tagged in this feasibility study must have reared in river habitats (i.e., "river-type" sockeye salmon), even though river-spawning sockeye salmon are often associated with 0-check or "sea-type" juveniles who migrate to sea soon after emergence (e.g., Gilbert 1913; Eiler et al. 1992). According to commercial catch data, 1% or less of Kuskokwim River sockeye salmon are 0-check (Molyneaux and Folletti 2005).

Age and Sex Composition

Of the 100 fish sampled for age information, 84 sockeye salmon had readable scales. Of these fish, age-1.3 was the most common age category (75.0%), followed by age-1.2 (16.7%), age-2.2 and age-2.3 (3.6% each), and age-1.4 (1.2%). The Aniak River fish were 88.9% age-1.3 and 11.1% age-2.2. The single Holokuk River fish was age-1.2. The Holitna River fish were 86.7% age-1.3, 11.1% age-1.2, and 2.2% age-1.4; no Holitna River fish had spent 2 years in freshwater. The Stony River fish were 56.3% age-1.3, 25.0% age-1.2, and 18.8% age-2.3. The single Swift River fish was age-1.3. The overall age composition in radiotagged sockeye salmon were similar to age compositions seen in commercial catch samples in 2005 (Molyneaux and Folletti 2005).

Only 29% of radiotagged sockeye salmon were females. The reasons for this low proportion are unknown, but may be due to selectivity of the fish wheels, poor sex determination by tagging crew, or to actual lower proportions of female sockeye salmon in the Kuskokwim River population. Future studies should take great care in determining the sex of tagged fish and should compare sex ratios with tributary populations.

Relative Run Timing

During this feasibility study, no attempts were made to spread tag deployment throughout the entire run. However, some insight into stock-specific run timing is possible even though sample sizes are small in later tagging periods. Aniak River sockeye salmon were more common later in the season, comprising 4.8%, 28.6%, and 57.1% of the first, second, and third tagging periods, respectively. The Holokuk River fish was tagged during the third tagging period. Holitna River sockeye salmon were more prevalent earlier in the season, and comprised 65.1%, 57.1%, and 28.6% of the first, second, and third tagging periods, respectively. Stony River sockeye salmon were also more common earlier in the run, and comprised 30.2%, 7.1%, and 0% of the first, second, and third tagging periods, respectively. The Swift River sockeye salmon was tagged during the second tagging period. This preliminary information suggests that Kuskokwim River sockeye salmon with longer migration distances may have earlier run timings.

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Conclusions and Recommendations

A full-scale sockeye salmon radiotelemetry project can be successfully executed in the Kuskokwim River drainage. In 2005, 88% of tagged fish successfully resumed upstream migration and 84% were successfully tracked to tributary spawning areas. These success rates are expected to improve after using the results from this feasibility study.

The hold time for sockeye salmon tagged from fish wheels in the Kuskokwim River should be less than one hour. In a full-scale study, this should be monitored closely in order to avoid detrimental tagging effects.

The model F1840 tag gives the best combination of expected battery life and small tag size for the range of sockeye salmon lengths found in the Kuskokwim River. However, fish <400 mm MEF length should not be tagged because of increased risk of stomach rupture. This is expected to exclude <7% of the sockeye salmon captured at the Kalskag fish wheels.

A high proportion of Kuskokwim River sockeye salmon may be "river-type," (i.e., juveniles rear in river habitats). This should be further evaluated in a full-scale study, since managers cannot necessarily apply knowledge gained from lake-type sockeye salmon populations from outside the Kuskokwim River as they may over- or under-estimate the productivity of the system.

This feasibility study suggests that the Holitna River drainage may be an important contributor to the Kuskokwim River sockeye salmon population. In light of possible natural resource development in Holitna and Hoholitna drainages, this should be further evaluated with the full-scale project.

References Cited

Burgner, R. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). In Pacific Salmon Life Histories. C. Groot and L. Margolis (eds). Vancouver: UBC Press, pp. 1-117.

Devries, D. R. and R. V. Frie. 1996. Determination of age and growth. In Fisheries Techniques. B. Murphy and D. Willis (eds). Bethesda: American Fisheries Society, pp. 483-513.

Eiler, J. H. 1995. A remote satellite-linked tracking system for studying Pacific salmon with radiotelemetry. Trans. Am. Fish. Soc. 124: 184-193.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by sockeye salmon in the Taku River, Alaska and British Columbia. Trans. Am. Fish. Soc. 121: 701-708.

Evenson, M. J., and K. G. Wuttig. 2000. Inriver abundance, spawning distribution, and migratory timing of Copper River chinook salmon in 1999. Alaska Department of Fish and Game, Fishery Data Series No. 00-32, Anchorage.

Gilbert, C. H. 1913. Age at maturity of the Pacific coast salmon of the genus *Oncorhynchus*. Report of the British Columbia Commissioner of Fisheries, 1912: 57-70.

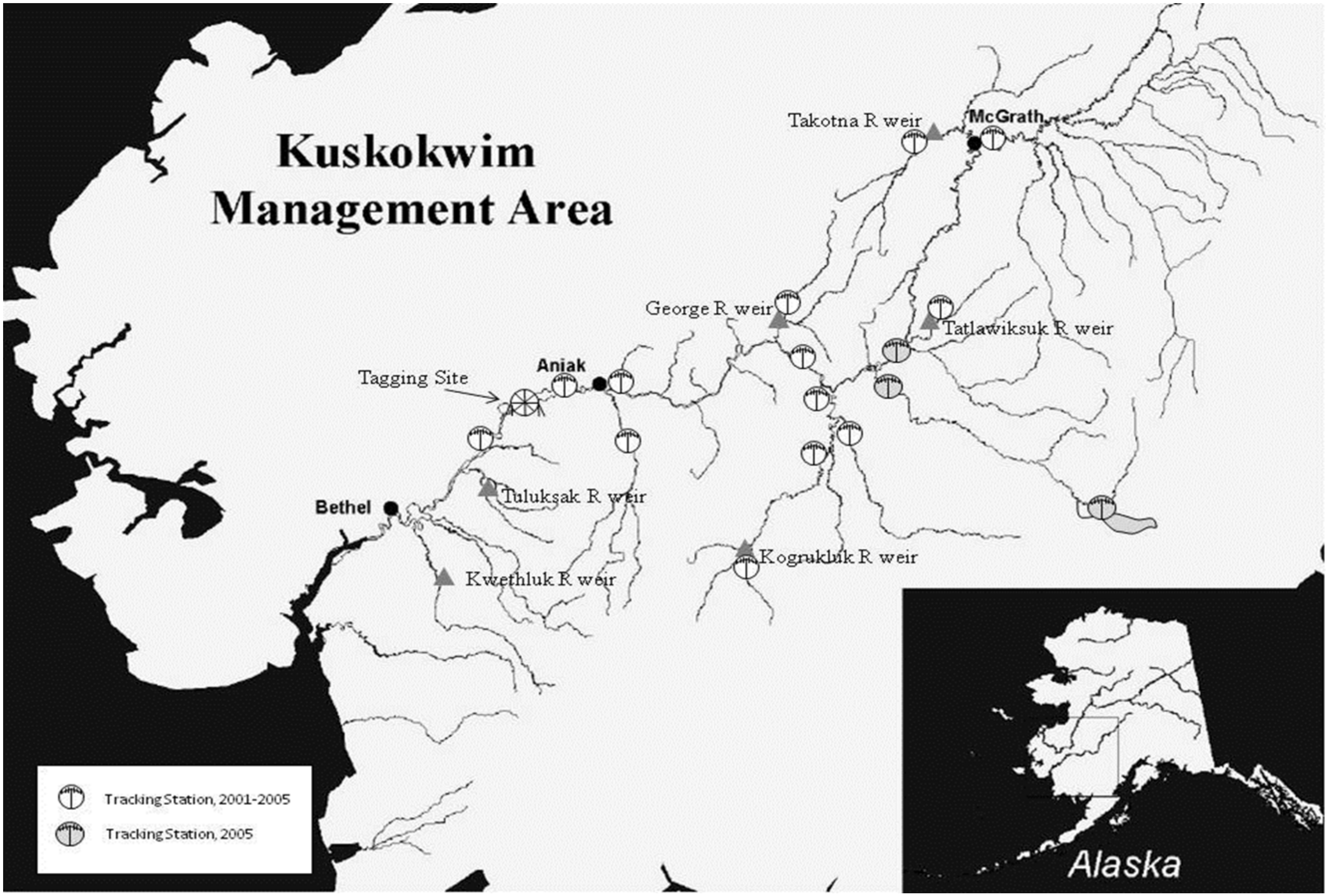
Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 1996. Tagging and marking. In Fisheries Techniques. B. Murphy and D. Willis (eds). Bethesda: American Fisheries Society, pp. 353-384.

Molyneaux, D. B., and D. L. Folletti. 2005. Salmon age, sex, and length catalog for the Kuskokwim Area, 2004. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A05-063, Anchorage.

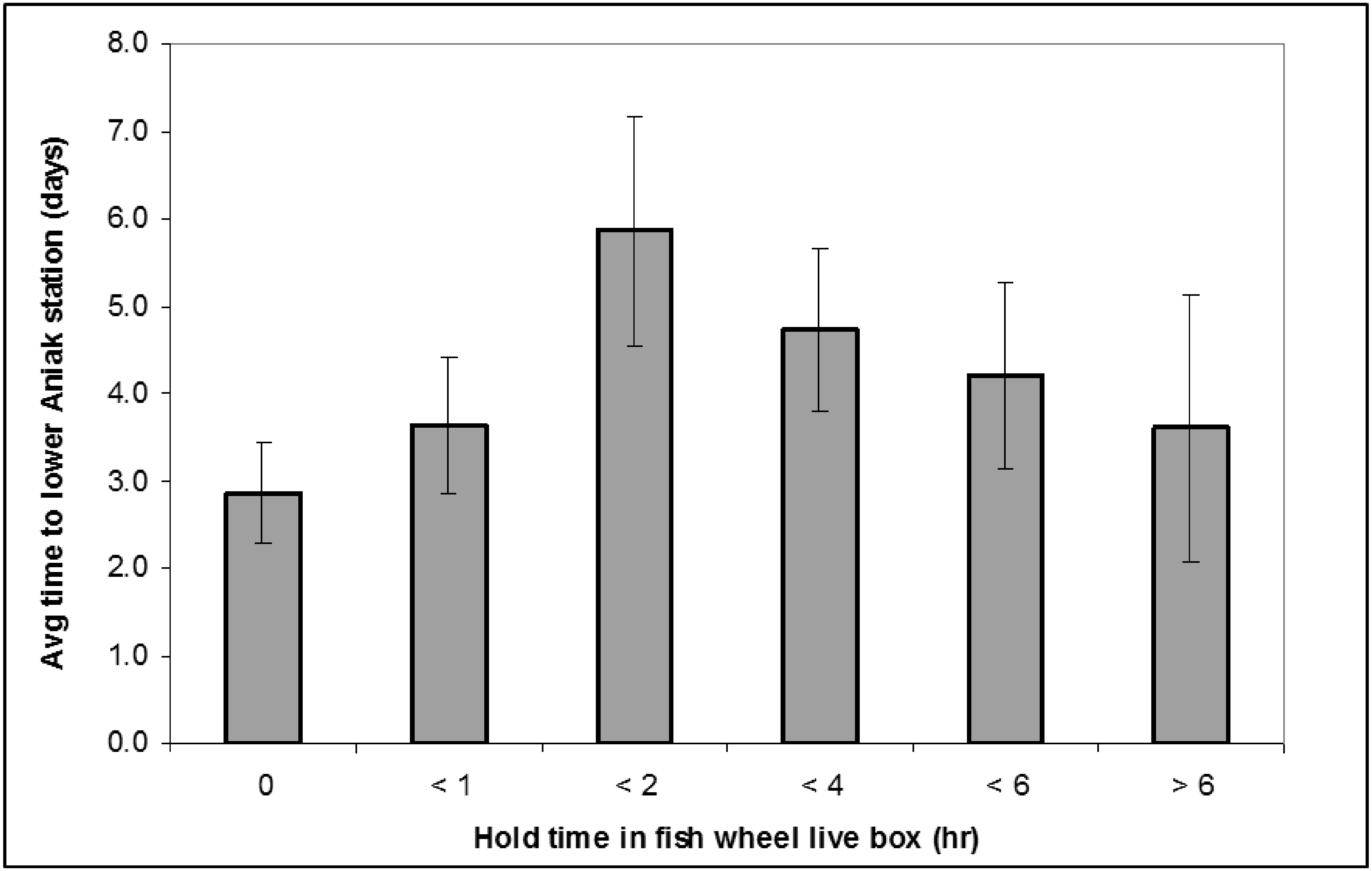
Stuby, L. 2005. Inriver abundance of Chinook salmon in the Kuskokwim River, 2002-2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-39, Anchorage.

Appendix Table 1.A.1.–Summary of sockeye salmon tag deployment in 2005 by tagging periods, bank of capture, capture method (fish wheels or drift gillnet), and tag model.

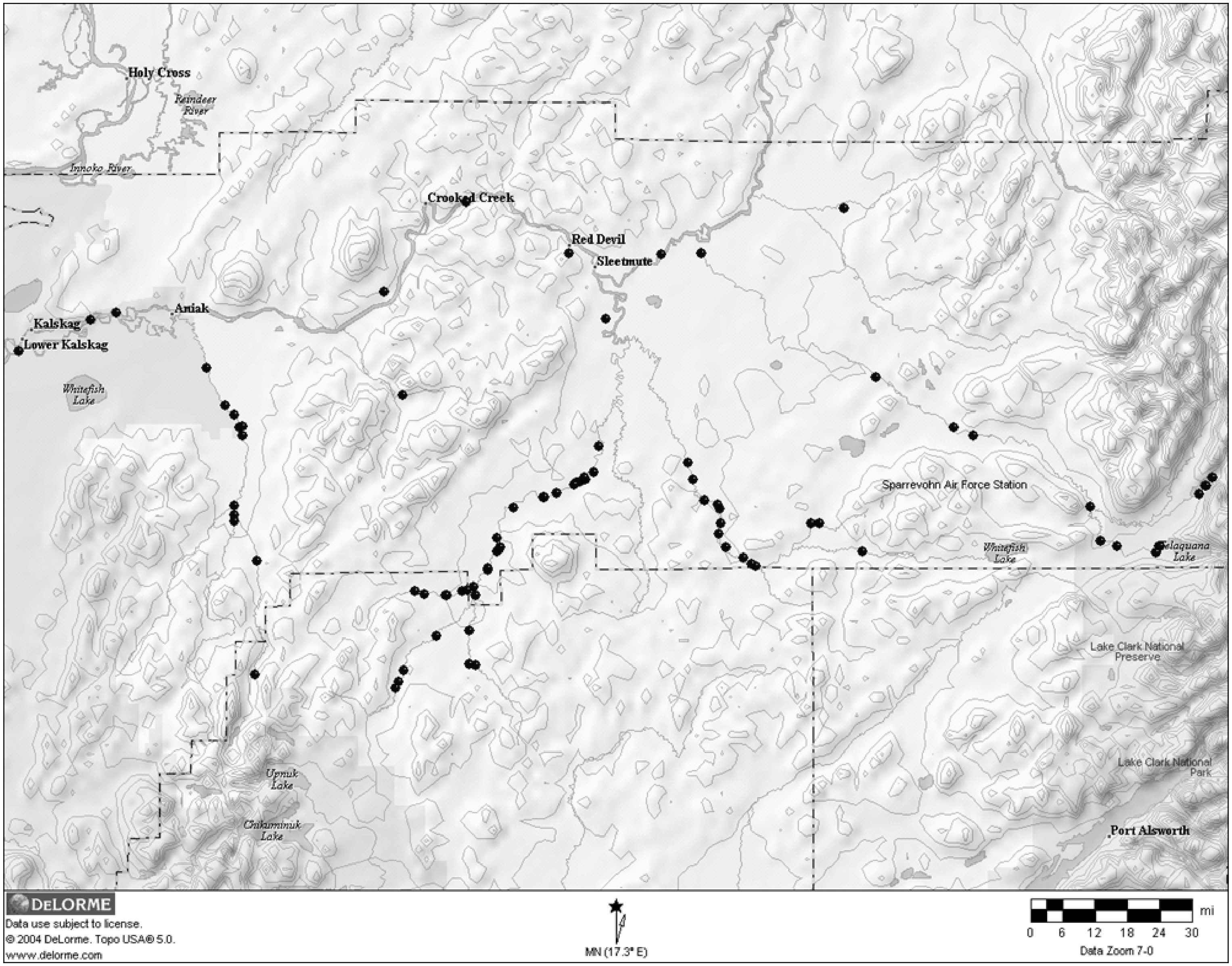
	North Bank			South Bank			Drift Gillnet		
	F1835	F1840	F1845	F1835	F1840	F1845	F1835	F1840	F1845
Period 1 (24 Jun – 1 Jul)	7	9	21	1	9	15	2	2	4
Period 2 (12 – 14 Jul)		9			10				
Period 3 (21 – 22 Jul)		7			4				
Total	7	25	21	1	23	15	2	2	4



Appendix Figure 1.A.1.–Kuskokwim River drainage with locations of escapement monitoring projects, tagging site, and ground-based tracking stations used in 2005.



Appendix Figure 1.A.2.–Average travel time to the first upstream tracking station (36 rkm from the tagging site) for sockeye salmon radiotagged in 2005 and held in fish wheel live boxes for various spans of holding times. Error bars indicate 90% confidence intervals.



Appendix Figure 1.A.3.–Farthest upstream location of Kuskokwim River sockeye salmon radiotagged in 2005.

APPENDIX 1.B: EXPLORATION OF ABILITY TO PROVIDE TOTAL ABUNDANCE ESTIMATES FOR KUSKOKWIM RIVER SOCKEYE SALMON USING MARK–RECAPTURE

Appendix 1.B.1.–Exploration of ability to provide total abundance estimates for Kuskokwim River sockeye salmon using mark–recapture.

Introduction

We explore the potential of using the approach of tag deployment and recovery described herein as a means to estimate total inriver abundance of Kuskokwim River sockeye salmon through a two-event mark–recapture experiment. The requirements for an unbiased estimate are that marked fish do not shed their tags and marked fish behave the same as unmarked fish. In addition at least one of the three following assumptions must be met: every fish has an equal probability of being marked during the first sampling event; every fish has an equal probability of being recaptured during the second sampling event; or marked fish mix completely with unmarked fish between sampling events. To test whether this project design was in violation of these conditions, we examined the marked-unmarked ratios at three recapture sites during the 2006 tagging study.

Methods

In 2006, dedicated tag recovery efforts to examine marked-unmarked ratios were conducted in three sub-basins: the Holitna, Aniak, and Stony rivers. These three locations were selected for more focused radio tag and anchor tag recovery effort based on findings from the 2005 feasibility study. Tag recoveries for the Holitna sub-basin occurred at Kogrukluk River weir, which includes a fish trap annually used to collect salmon age-sex-length data (Liller et al. 2008). Recoveries in the Aniak and Stony sub-basins were attempted through systematic beach seining over a period of six weeks, with a target of 24 seine hauls per week. Recovery crews recorded the total number of fish by species, and the number of radiotagged and anchortagged fish in each seine haul or each day's weir passage. A chi-square test was used to test the hypothesis that probability of recapture is constant among recovery sites (Sokal and Rohlf 1995).

Abundance estimates were made using radio tags only. The mark–recapture estimate used tags deployed at Kalskag and recaptured at the Kogrukluk River escapement monitoring project (i.e., fish wheel and weir). Abundance estimates were generated using the Chapman estimator and parametric bootstrap estimates of confidence intervals (Efron and Tibshirani 1993).

The Chapman abundance estimator (Seber 1982) based on tag recaptures was calculated as:

$$\hat{N}* = \frac{(C+1)(M+1)}{R+1} - 1 \tag{1}$$

where:

- $\hat{N}*$ = estimated abundance of salmon in the Kuskokwim River at the Kalskag site,
- M = the total number of salmon tagged at the Kalskag site,
- C = the total number of salmon examined at the Kogrukluk River recapture weir project, and
- R = the total number of tagged salmon recaptured at the Kogrukluk River escapement project.

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Results and Discussion

Sockeye salmon abundance in the Kuskokwim River upstream of Kalskag in 2006 and 2007 was estimated to be 445,860 and 124,336 respectively (Table B1.1). At Kogrukluk River weir, 59,773 fish were observed, including 380 radiotagged or anchortagged sockeye salmon. Beach seining in Telaquana River resulted in a catch of 1,757 sockeye salmon, of which 11 were tagged. Poor water conditions in the Aniak River resulted in only 19 sockeye salmon being captured in the beaching seining, none of which were tagged; consequently, the Aniak River was dropped from further mark–recapture evaluation. No significant difference was found in the marked-unmarked ratios between the Kogrukluk and Telaquana sites (χ^2=0.003, df=1, P=0.96), suggesting the fish had an equal probability of capture at the Kalskag tagging site, and that our study design was not in violation of at least one condition required for an unbiased 2-event mark–recapture experiment.

Although not one of the original objectives of this project, it appears possible to use mark–recapture to estimate total sockeye salmon abundance in the Kuskokwim River. We used our findings to estimate total inriver abundance in 2006 and 2007 to provide some indication of the possible magnitude of total sockeye salmon abundance in the Kuskokwim River (Table B1.1). While we acknowledge limited diagnostic capacity to bolster confidence in these estimates our methodology did appear to perform adequately. Given the level of genetic differentiation that exists among some sockeye salmon populations, it may also be possible to use genetic markers as a means of estimating total abundance, similar to the approach described by Beacham and Wood (1999) and Beacham et al. (2000). Such an approach would require collecting total abundance estimates for a genetically distinct stock as may be possible using a weir at the outlet of Telaquana Lake.

The diagnostics suggest that the tagging methods employed in this study do provide a promising means to estimate total Kuskokwim River sockeye salmon abundance using mark–recapture techniques. Total abundance can be calculated by adding estimated abundance upstream of Kalskag, estimated sockeye salmon escapement in tributaries downstream of Kalskag, and harvest in lower river fisheries. From this, the total abundance of Kuskokwim River sockeye salmon is estimated to be 503,452 in 2006 and 169,569 in 2007 (Table B1.2). We estimate an annual exploitation rate of 9% in 2006 and 20% in 2007. This is much lower than exploitation rates in Bristol Bay, which typically exceed 50% (Salomone et al. 2007), but may have been higher in the past (Figure B1.1). However, in the face of expanding fishery demands, it would be essential for managers to better understand the dynamics of both river- and lake-type sockeye salmon in the Kuskokwim River in order to preserve the biocomplexity that will likely be responsible for their sustainability under changing environmental conditions.

The total inriver abundance and exploitation rates varied between 2006 and 2007, partially due to the near record sockeye salmon run size in 2006. The Holitna River was the major producer of sockeye salmon, followed by the Stony River drainage, and these two systems seem to be dominated by salmon following very different life history patterns. This raises the question of the stability of relative abundance of river-type or lake-type sockeye salmon. In order to harvest sustainably, managers will need to develop stock assessment projects to monitor escapement in a manner that incorporates sockeye salmon population diversity. At a minimum, management

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should strive to monitor both river-type and lake-type life history strategies within the Kuskokwim River. Future work could include tag recovery in both the Holitna River (Kogrukluk River weir) and Stony River (Telaquana Lake) drainages for estimating Kuskokwim River sockeye salmon abundance while still incorporating both life history types.

References Cited

Bavilla, J., D. Bue, H. Carroll, T. Elison, D. Taylor, and J. Estensen. 2010. 2009 Kuskokwim Area Management Report. Alaska Department of Fish and Game, Fishery Management Report No. 10-56, Anchorage

Beacham, T. D. and C. C. Wood. 1999. Application of microsatellite DNA variation to estimation of stock composition and escapement of Nass River sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 56:297-310.

Beacham, T. D., C. C. Wood, R. E. Withler, K. D. Le, and K. M. Miller. 2000. Application of microsatellite DNA variation to estimation of stock composition and escapement of Skeena River sockeye salmon (*Oncorhynchus nerka*). N. Pac. Anadr. Fish Comm. Bull. No. 2:263-276.

Efron, B., and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, New York.

Liller, Z. W., D. J. Costello, and D. B. Molyneaux. 2008. Kogrukluk River weir salmon studies, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 08-26, Anchorage.

Salomone, P., S. Morstad, T. Sands, C. Westing, T. Baker, F. West, and C. Brazil. 2007. 2006 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 07-22, Anchorage.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, second edition. Edward Arnold, London.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research. 3rd ed. New York: W.H. Freeman and Company, 887 pp.

Appendix Table 1.B.1.–Abundance estimation for Kuskokwim River sockeye salmon using the Chapman estimator and parametric bootstrap estimates of confidence intervals.

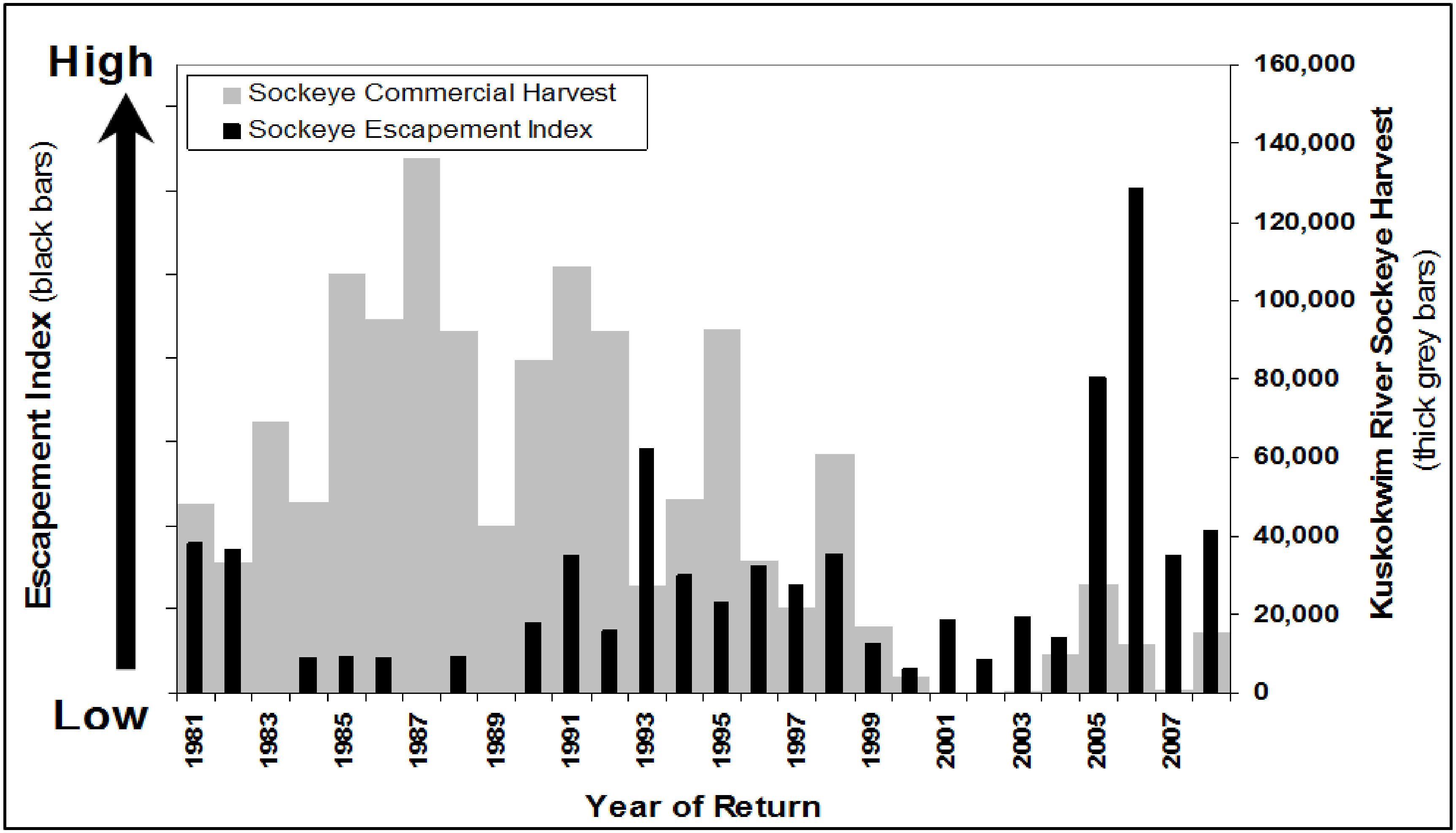
Year	Location	Estimate	Std. Err.	95% CIL	95% CIU
2006	Kuskokwim R. above Kalskag	445,860	58,200	351,762	584,743
	Holitna R.	259,904	40,054	188,082	351,633
2007	Kuskokwim R. above Kalskag	124,336	18,765	93,821	166,341
	Holitna R.	68,245	7,998	48,709	92,549

Appendix Table 1.B.2.–Total run estimates and exploitation rates in 2006 and 2007 for Kuskokwim River sockeye salmon.

Run Component		Method	2006	2007
Harvest				
	Subsistence		30,226	33,234
	Commercial		12,618	703
	Sport		231	382
	Total		43,075	34,319
Escapement				
	Mainstem upstream of Kalskag	Radiotelemetry	445,860	124,336
	Kwethluk	Weir	6,732	5,262
	Kisaralik	Estimate [a]	6,800	5,300
	Tuluksak	Weir	985	352
	Total		460,377	135,250
Total Abundance			503,452	169,569
Annual Exploitation			9%	20%

Note: Annual harvest and weir escapement estimates from 2009 Kuskokwim Area Annual Management Report (Bavilla et al. 2010)

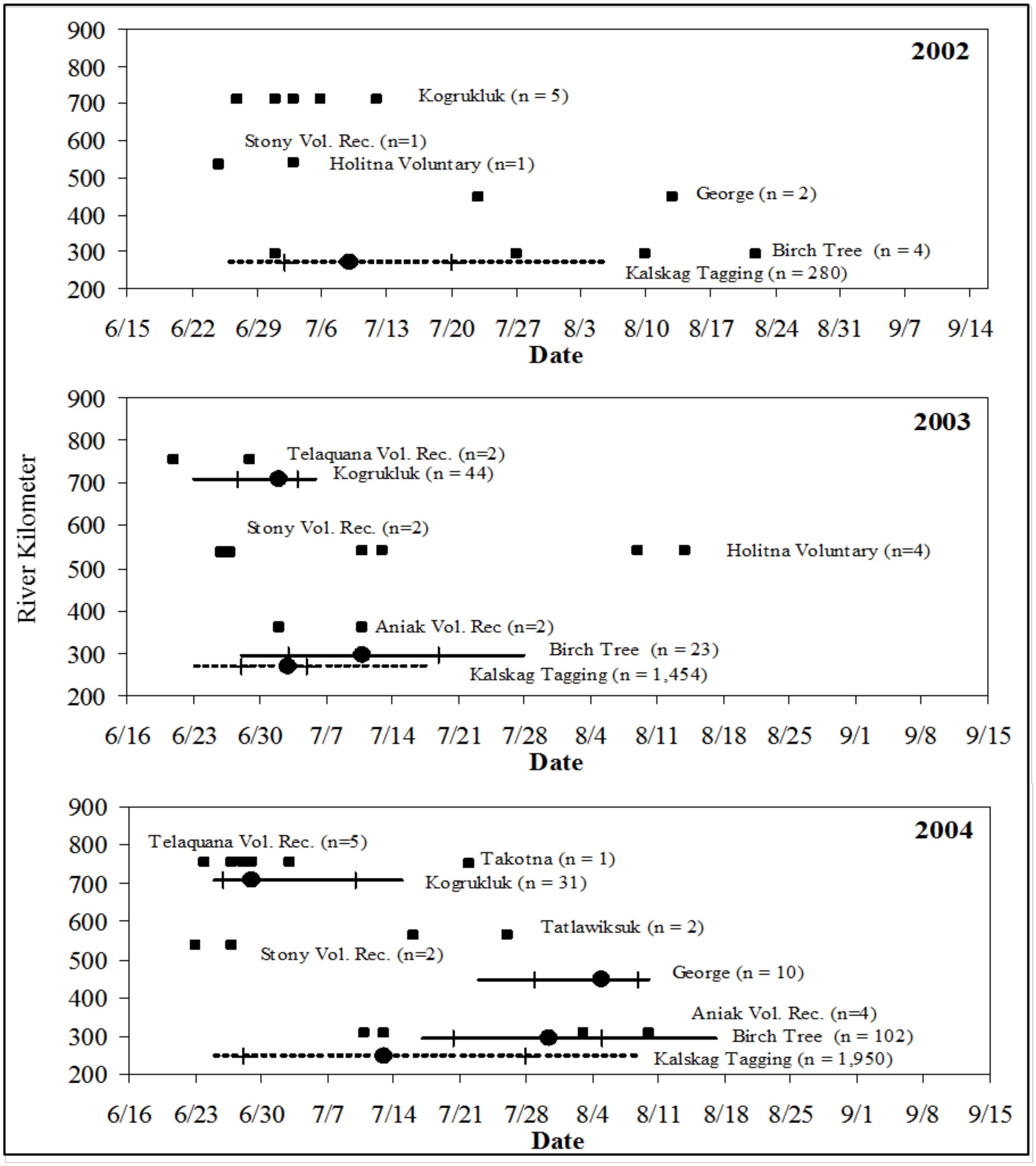
[a] The Kwethluk River weir passage was used as a surrogate for the Kisaralik due to similarity in basin size and morphology.



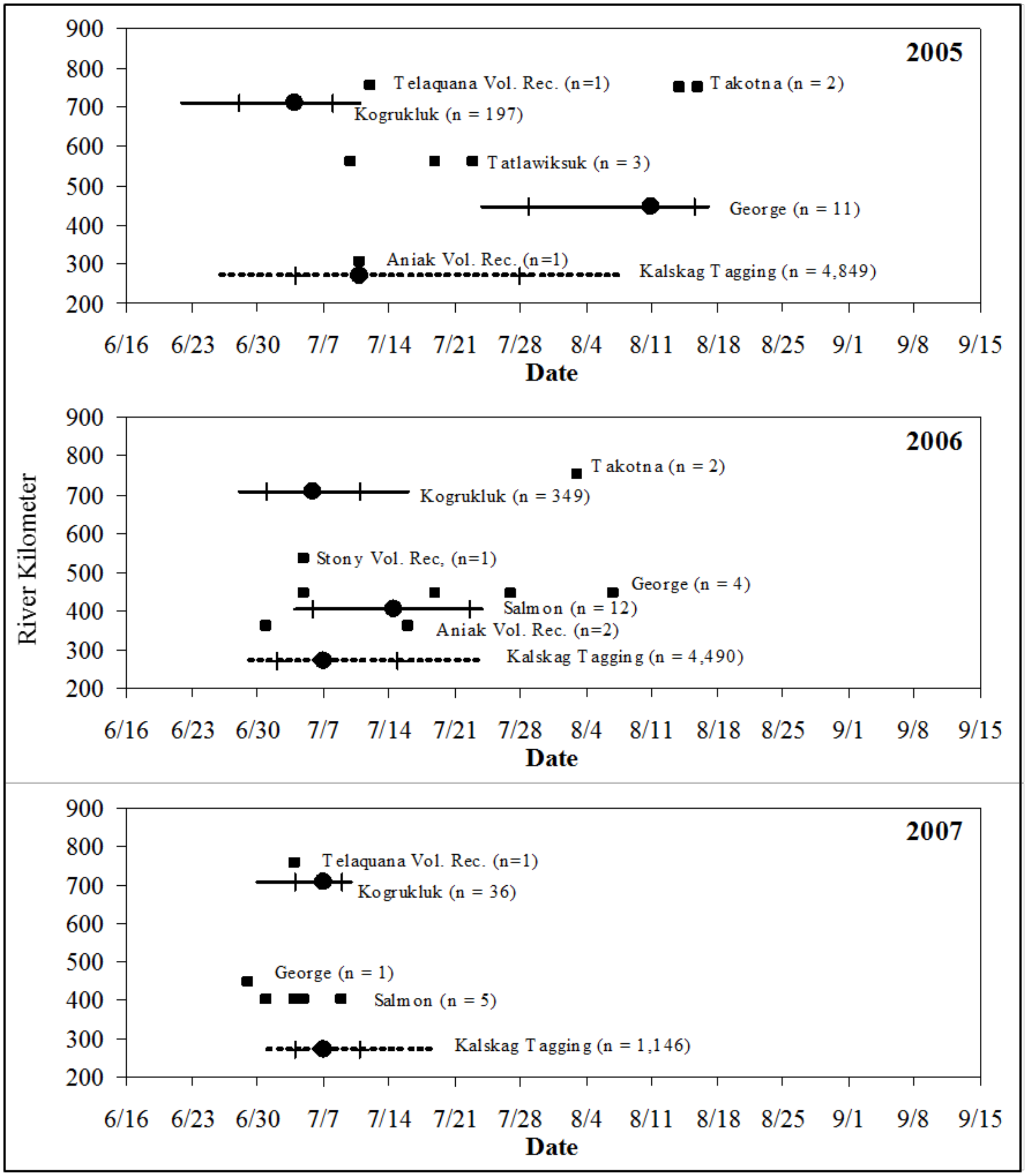
Note: Escapement indices are based on annual Kogrukluk River weir sockeye salmon passage.

Appendix Figure 1.B.1.–Annual escapement index and commercial harvest of Kuskokwim River sockeye salmon.

APPENDIX 1.C: HISTORICAL KUSKOKWIM RIVER SOCKEYE SALMON RUN TIMING



Appendix Figure 1.C.1.–Stock-specific run timing for sockeye salmon anchortagged in 2002–2004, including median (circle), quartile (vertical lines), and 10th and 90th percentile dates (horizontal line). Squares are tagging date for individual fish in tributaries with <5 recovered tags.



Appendix Figure 1.C.2.–Stock-specific run timing for sockeye salmon anchortagged in 2005–2007, including median (circle), quartile (vertical lines), and 10th and 90th percentile dates (horizontal line). Squares are tagging date for individual fish in tributaries with <5 recovered tags.